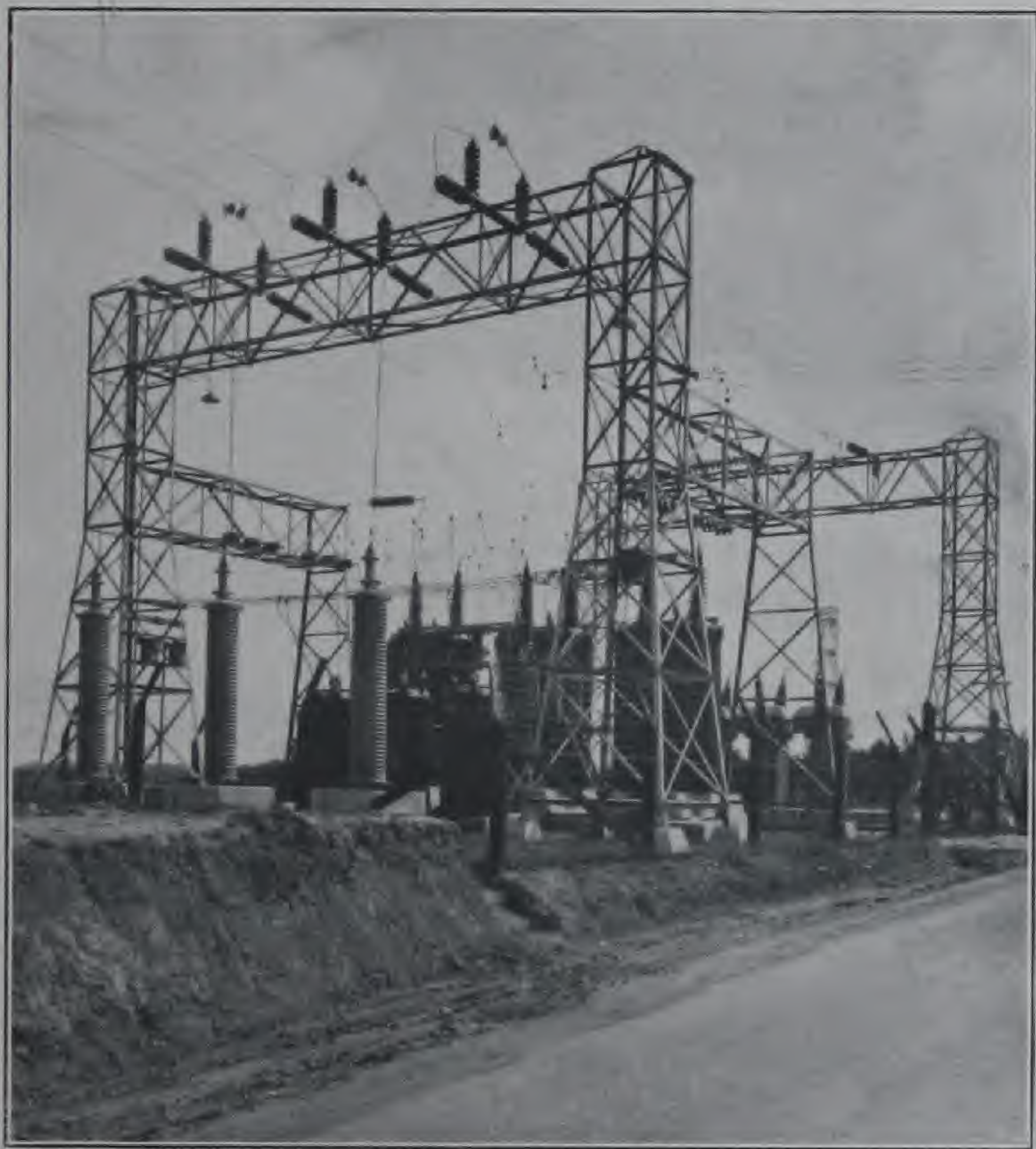
Bulletin 601

Bennett Lightning Arresters



ELECTRIC POWER EQUIPMENT CORPORATION

AGENTS IN PRINCIPAL CITIES

APRIL, 1924

ELECTRIC POWER EQUIPMENT CORPORATION
ELPECO
PHILADELPHIA, PA.

Introducing

BENNETT LIGHTNING ARRESTERS

Now and henceforth produced exclusively by
ELECTRIC POWER EQUIPMENT CORPORATION

THE Bennett Lightning Arrester, while a radical departure from other devices of similar purpose, is not an experiment. It is, on the contrary, soundly conservative in principle and measured by the standard of practical performance in many heavy-duty installations, is the equivalent of an old established success in service. So much for what it *has* done.

Now for what it *will* do. The majority of you who read this are users of "ELPECO" Equipment. You know exactly what it means when we assure you that our reputation is pledged squarely and without reservation on the worthiness of the Bennett Lightning Arrester as a unit of the "ELPECO" Line.

To the diminishing minority without personal experience with "ELPECO" Equipment, you may write your own guarantee. Start with this thought as a basis.

We guarantee the Bennett Lightning Arrester, when properly installed, to function to your entire satisfaction under any practical service condition; with equal precision whether indoors or out; in wet weather or dry; with a closer setting of arc-gap, resulting in a higher degree of protective efficiency than any other device of similar purpose.

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Details of Construction
Bennett Lightning Arresters

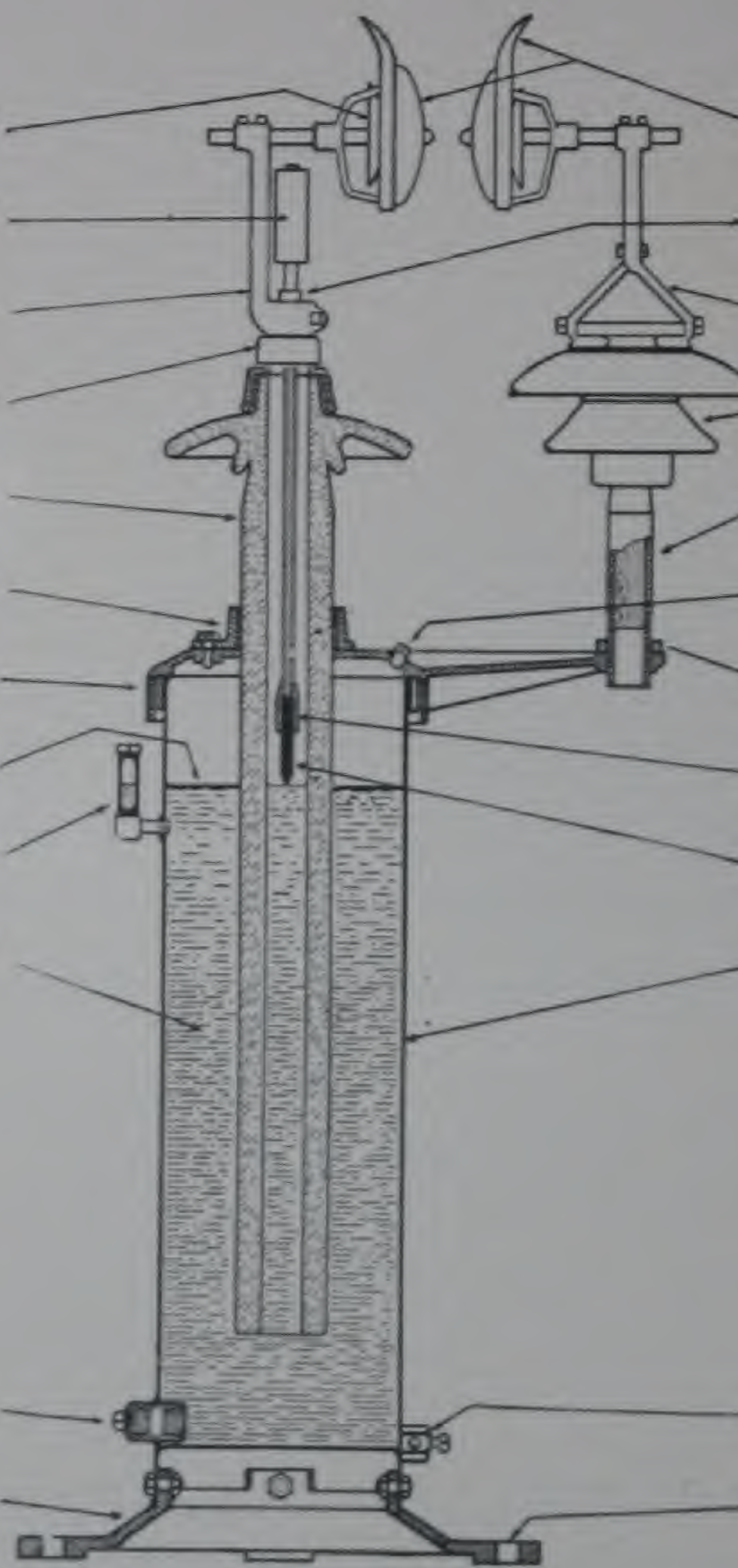


Figure 1
Cross Section of D-24 Bennett Arrester

All Bennett Lightning Arresters operate on the same simple basic principle—the water path to ground giving free passage to high frequency discharges, and the vapor cushioning effect whereby heavy surges are given a tapering discharge.

While this principle is common to all Bennett Lightning Arresters, a wide variation of engineering requirements necessitates a corresponding variation in the outward form of the different types of Bennett Arresters.

Naturally, the increased voltage of the largest sizes demands heavier construction and larger equipment, which is provided.

Details of Construction—*Continued*

Figure 2
The Parts of a Complete Unit

Tanks are of Armco iron with joints securely welded which makes them practically indestructible. All upright tanks have a heavy cast iron base and top-ring. A reinforced cover is placed on top of the tank and securely bolted thereto. This cover provides a support for the bushing and also for the pin and insulator which carry both the incoming line and one side of the gap.

Tanks and iron castings have a protective coating of zinc, applied by hot-dip process. Small parts are made of brass to prevent rusting.

DISC GAPS

The engineer, appreciating as he does, supreme efficiency, regardless of the field of accomplishment in which it may occur, will find the Disc Gaps of the Bennett Lightning Arrester worthy of his sincere admiration.

Figure 3
Phantom View of Disc Gap Unit

Details of Construction—*Continued*

Figure 4
Disc Gap on Type D-44

Having been properly spaced for normal service conditions, the Bennett Disc Gap thereafter not only functions automatically, but with infallible self-adjustment to weather conditions, whether drought or downpour. This is accomplished by the absorption of water by the disc of refractory porcelain.

The small rounded terminal at the center of each unit is surrounded by a curved disc or specially fired refractory porcelain which closely resembles lava insulation. Like lava, the disc itself easily withstands a heat which would fuse metal.

When dry, the porcelain disc is an insulator; when wet, it absorbs water and becomes a conductor sufficiently to redistribute the flux across the gap. In effect, the gap functions like small spheres when dry, and like large spheres when wet. This automatically compensates for the lower arc-over voltage which the small spheres would have otherwise, and the wet and dry arc-over voltages are substantially the same.

For the foregoing reasons, the Bennett Disc Gap can be set much closer than others, with the assurance that the arrester will not be continuously discharging during every rain storm. This closer gap setting means an important increase in protective efficiency.

Details of Construction—*Continued*

When the discs are dry, the metal shield behind each disc makes the gap even more sensitive to impulse voltages than it is to 60 cycle voltage. Tests have shown a breakdown under impulse voltage of less than 70% of the 60 cycle arc-over voltage. It is readily understood how valuable this makes the disc gap in discharging surges due to the heavy lightning which frequently precedes the breaking of the storm.

BUSHINGS

The function of the bushing unit in the Bennett Lightning Arrester is to provide, within the main tank, a condition whereby the point of the carbon electrode makes electrical contact with the solution within a chamber of relatively limited dimension.

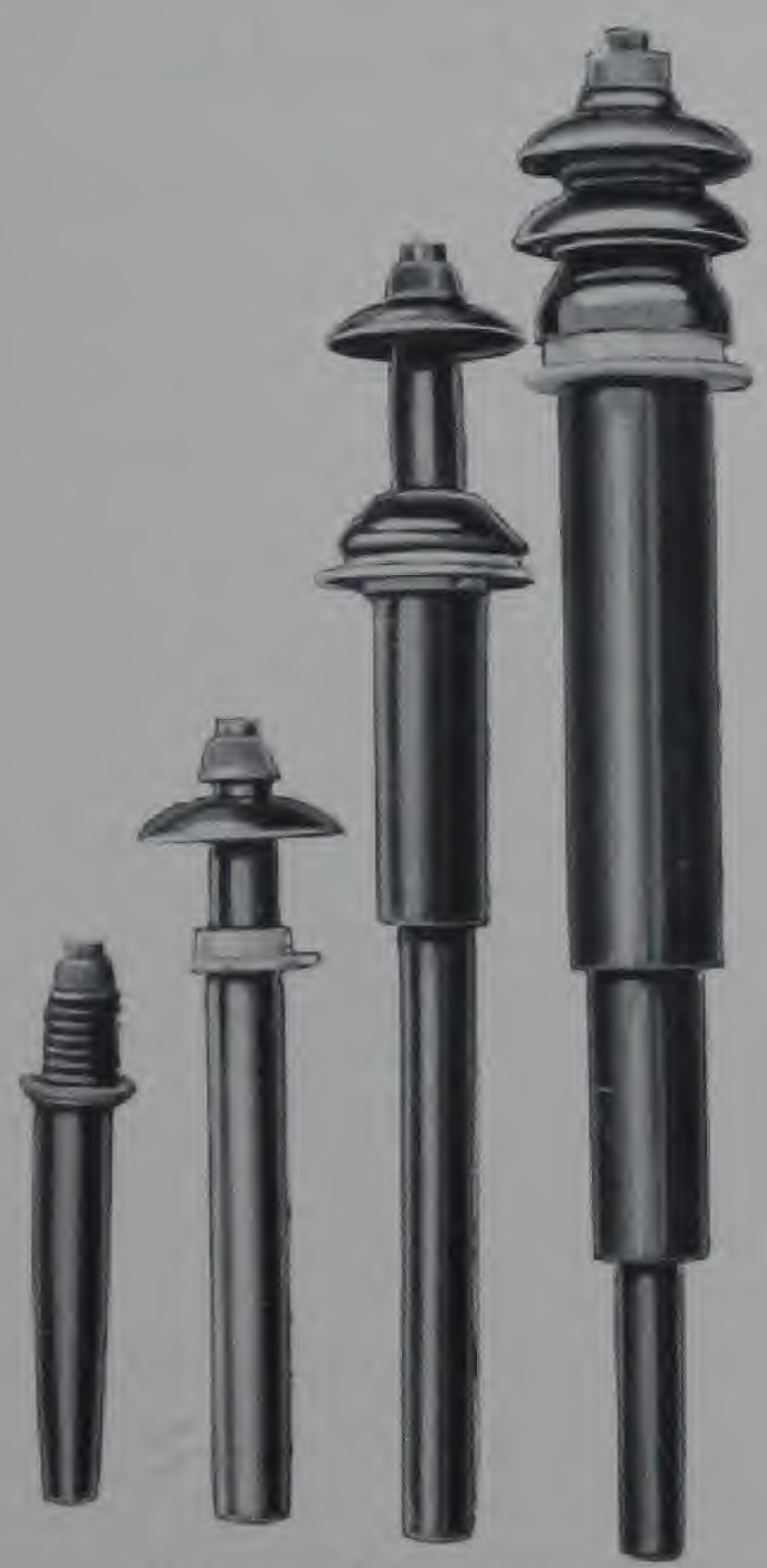


Figure 5. Bushings

The cushioning action of the Bennett Arrester is accomplished by vaporizing the solution at point of contact with electrode, by the impact of the discharge, passing from the disc gaps through the tank to the ground.

Details of Construction—*Continued*

It is obvious that vaporization will be tremendously accelerated—in point of time—by restricting the action to a small column of solution rather than to the entire volume of solution in the tank.

Hence, the insulating walls of the bushing provide a condition that may be broadly compared to a micrometer effect as regards vaporization, while the open bottom of the bushing provides a free path for the discharge to the ground connection.

Further details of this feature of operation is shown in connection with Figs. 8 and 9 on page 10.

The bushing is made of non-porous porcelain of the finest grade. The tube is continuous for its entire length.

For the higher voltages, additional insulation is provided in the larger sizes by porcelain sleeves outside the main tube, as shown.

The bushing flange and the ring upon which is screwed the bushing cap, are permanently attached to each bushing.

Figure 6. Insulator

INSULATORS

The insulator which supports the incoming disc unit is mounted upon a pin with standard thread. The 25,000 volt arresters have insulators rated at 45,000 volts. For other voltages the insulators are in like proportion.

Details of Construction—*Continued*

Figure 7. Electrode and Mounting

ELECTRODE

The electrode is solid carbon, one-half inch in diameter and four inches long. This is clamped to the electrode rod which is a tube leading up through the bushing to a breather chamber. The breather equalizes the fluctuations of air pressure resulting from vaporization at point of contact of electrode with solution.

The wall of the tube, or electrode rod, also serves as a conductor to carry the incoming surge down from the disc gap to the electrode.

NON-FREEZING SOLUTION

It is obvious that the solution in the tanks of Bennett Lightning Arresters must not be permitted to freeze. Accordingly, we are prepared to furnish a special non-freezing solution for any installation involving freezing hazard where temperatures as low as 25 degrees below zero are possible.

It is advisable that solution be furnished to meet the particular conditions of each installation where freezing hazard exists.

FOR TEMPERATURES BELOW 25 F.

For installations where temperatures lower than 25 degrees below zero are possible, we can furnish tanks lagged with felt and equipped with an electro-thermal heating element.

Cycle of Operation
Bennett Lightning Arresters

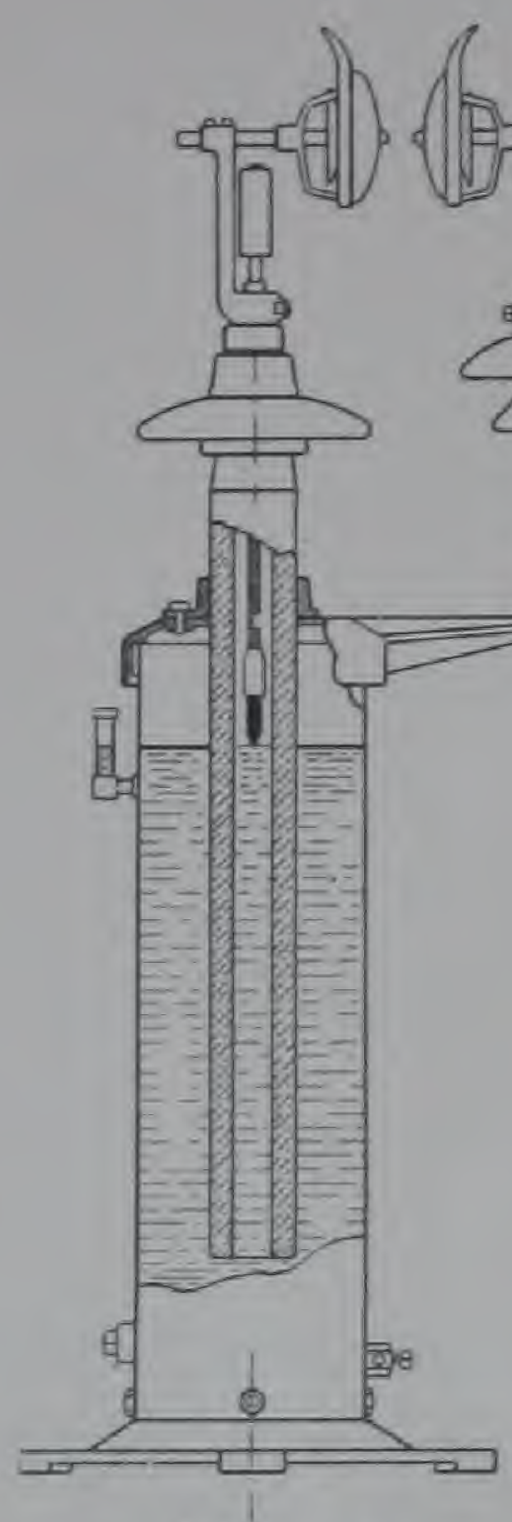


Figure 8
Cross Section (Normal)

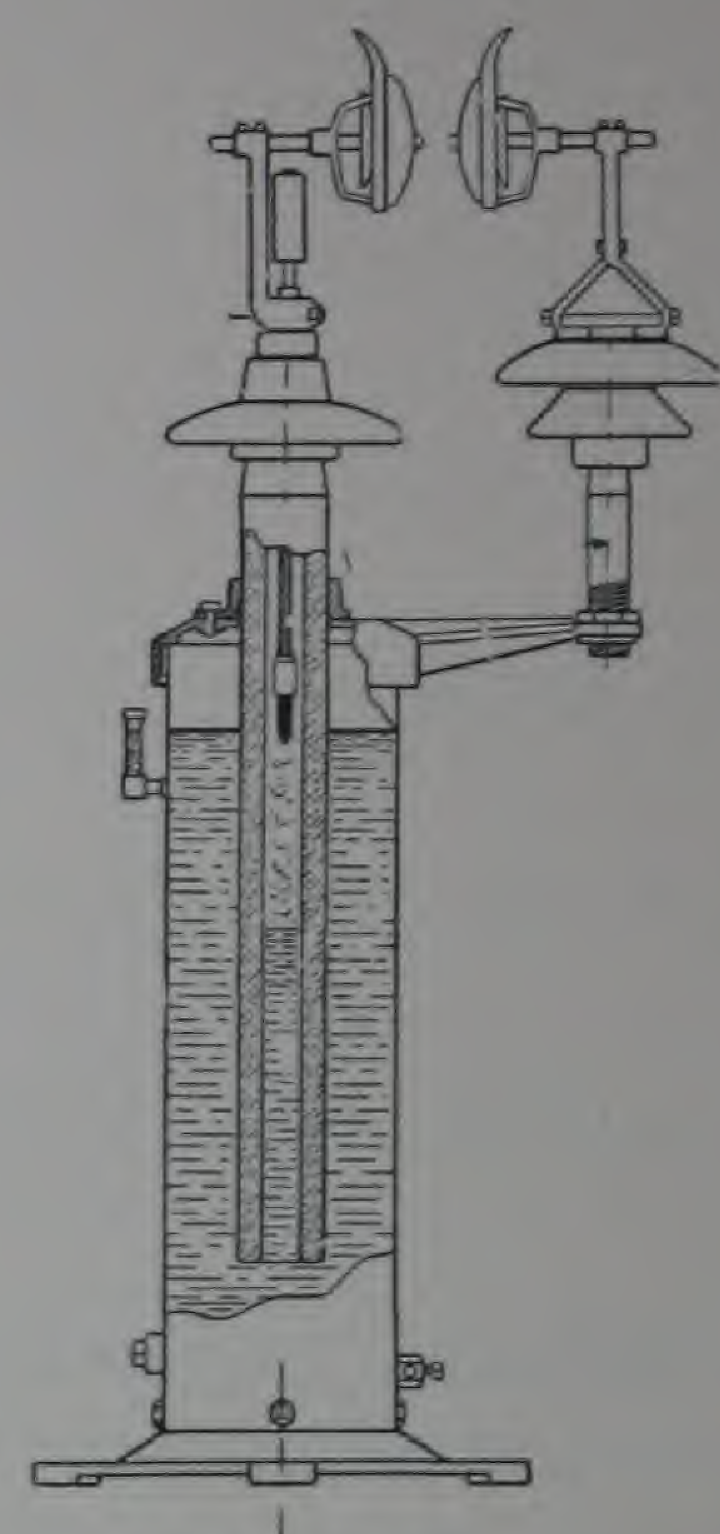


Figure 9
Cross Section (Discharging)

At the instant of discharge the current spans the arc-gap and is carried directly down the electrode rod through the carbon electrode to the solution column inside the bushing. This solution column offers a non-inductive path through which the high voltage discharge is carried directly to the ground connection.

When the dynamic current follows a discharge across the gap, the resistance of the solution column in the tube is sufficient to prevent an undesirably heavy flow of dynamic current to the ground.

As the discharge continues, the solution in contact with the carbon electrode becomes rapidly vaporized and sufficient pressure is developed to press the solution column downward inside the porcelain tube, the space formerly occupied by the solution being taken up by a conducting vapor of much higher resistance. (See Fig. 9.)

When enough of this vapor has been interposed in its path, the current is so reduced in value that the arc at the outside gap cannot be maintained and current flow ceases.

Operation—*Continued*

The portion of the tube where this action occurs is entirely submerged in the solution contained in the tank, and is, therefore, kept cold regardless of the action of the arrester. This assists materially in the interruption of the current flow and also causes the pressure within the tube to be dissipated by condensation of the vapor formed during the discharge. There is also promoted a vacuum within the tube, causing the solution to instantly rise to its normal level when the discharge has ceased.

In usual practice, the electrode is set so that its tip penetrates the solution about one-quarter inch. If set deeper than this, the action is the same as described, but slower, in proportion to the depth of electrode. The deeper the electrode, the more solution must be vaporized; hence the time lag.

This slower operation is preferred by some operators, but in most cases it is preferable to have the quick operation.

Note that the arrester gives complete protection and checks the subsequent flow of dynamic current with the same action, regardless of which way the electrode may be set, only the time element being affected.

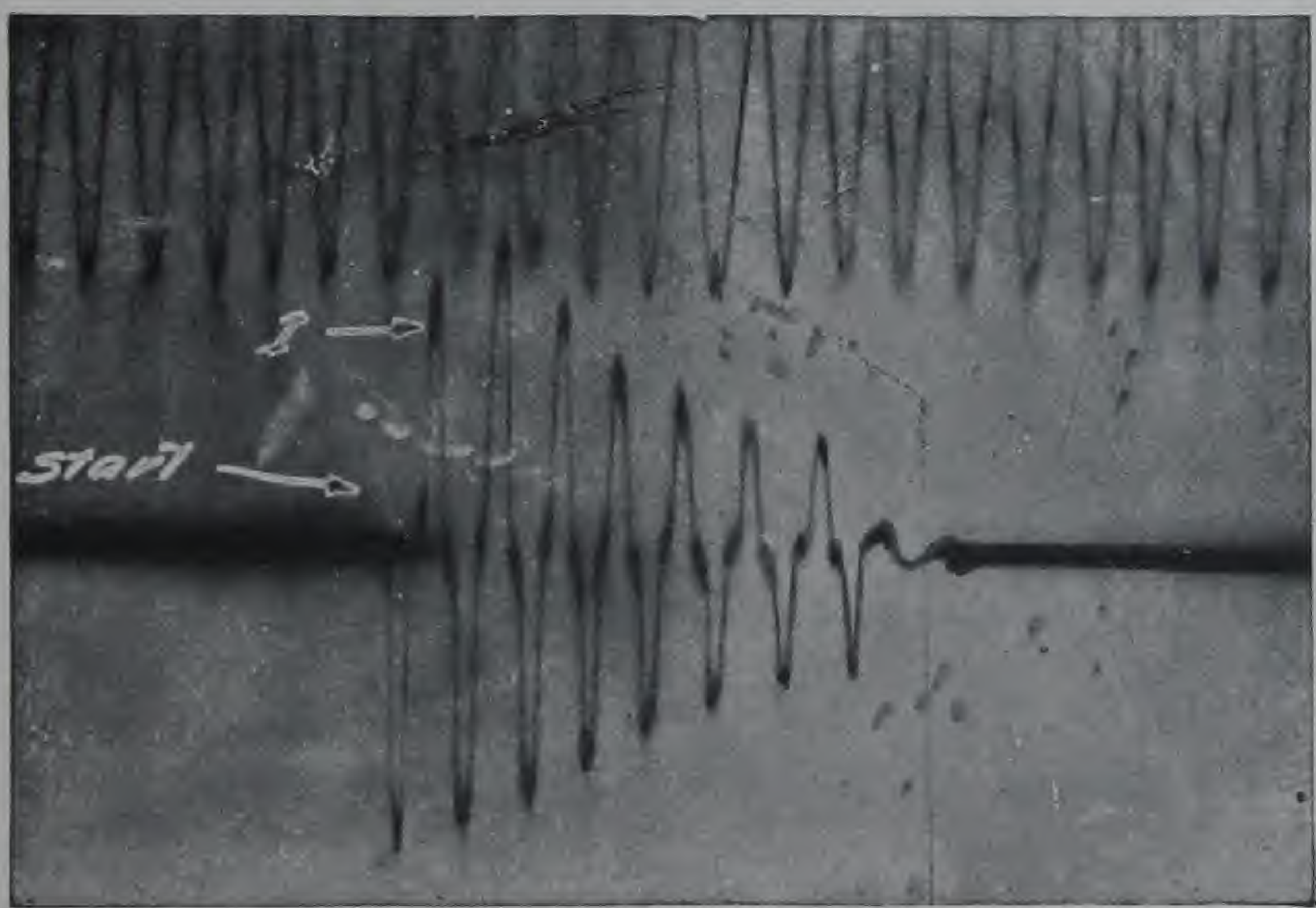


Figure 10. Oscillogram of Normal Discharge

The oscillogram shown, Fig. 10, is from a test made to determine the flow of dynamic current following a discharge. The arrester carries maximum current during the first few cycles. Then as the solution is driven downward in the tube, the current is uniformly reduced until it is finally interrupted at the gap in approximately 1/10-second. This tapered action when interrupting a current is a very important characteristic of the Bennett Lightning Arrester. This is the principle which enables it to relieve an excessively heavy discharge from a line without causing any reaction on the system.

Operation—*Continued*

The Arrester can be experimentally subjected to as many discharges in a few minutes as would occur in normal service through many years. Each discharge, however great, has short duration, and the time-energy involved is small. Several hundred successive discharges do not materially raise the temperature of the solution. This Arrester has so great a capacity for dissipating energy that it may be adjusted to meet any operating requirements.

In some generating stations it has been found advisable to protect the busses and circuits against surges of high potential, with arresters of heavy current capacity. Since the Bennett Arresters are installed without fuses, they are particularly suitable for this purpose.

NO FUSES REQUIRED

Bennett Lightning Arresters cannot be harmed by continuous discharge, as they cannot be heated to the point of destruction. If, from any cause, the gaps are short-circuited and line voltage is imposed on the Arrester continuously, the Arrester will suffer no damage, since it will automatically open the circuit within itself. This action comprises a boiling away of sufficient solution to prevent actual contact with the electrode when the solution column returns to its normal static level.

This does not mean that the Arrester is out of service, for should a subsequent discharge of a higher voltage occur, the gap having been created between the electrode and the surface of the solution will be bridged and the Arrester will act normally.

It will be seen from this that fuses are not necessary with this Arrester, nor would they serve any purpose whatsoever in protection. A fuse in the circuit of an arrester usually blows at a time when the arrester is most needed, which is also the time when the operator may be unwilling to replace the fuse promptly. Therefore, in no instance do we recommend fuses for use with Bennett Lightning Arresters.

NO FIRE HAZARD

Having no fire hazard, the Bennett Lightning Arrester may be installed on station roof or in a switch room without danger to adjacent structures or apparatus. They are peculiarly suitable for protecting the separate low voltage circuits of exciters and other auxiliaries in the large modern station.

ADAPTABILITY

The discharge rate for high potential surges increases as the superimposed voltage becomes greater, but in all types of Bennett Lightning Arresters the rate

Operation—*Continued*

of discharge at line voltage may be controlled by merely modifying the water solution. The rate should be comparatively high, but should not place an undue load on the line. The Arresters function properly over a wide range of adjustment, and therefore only the conditions of the system need be considered.

Any Bennett Arrester may readily be arranged for operation on a voltage lower than regular rating, by simply increasing the density of the solution and adjusting the gaps; and it can as easily be readjusted again. Each single-pole unit is complete in itself, and they may be installed as required in two-pole, three-pole or four-pole sets.

WATER AS A CONDUCTOR

The skin effect is so much less with water than with any metal that it is negligible in a water column of small diameter. Conversely, the penetration of high frequency current through the entire mass of the conductor is greater, as shown by the following figures, which are quoted from Dr. Steinmetz:

PENETRATION IN CM.

At 60 Cycles	
Copper	.82
Salt Solution (conc.)	1,450
Pure River Water	65,000
At 10,000 Cycles	
Copper	.64
Salt Solution (conc.)	112
Pure River Water	5,030
At 1,000,000 Cycles	
Copper	.0064
Salt Solution (conc.)	11.2
Pure River Water	503

The solution used in Bennett Lightning Arresters is seldom over 1½ per cent of saturation; therefore, there is offered a path for high frequency currents that is ideal.

VAPOR AS A CONDUCTOR

The vapor formed inside the bushing in the Bennett Lightning Arrester has a definite conductivity, although this conductivity is considerably less than that of the solution. Therefore, the current path inside the bushing is never interrupted.

Operation—*Continued*

Tests clearly demonstrate that even when high frequency current is continuously applied, it finds a continuous discharge path through the Arrester, regardless of the momentary position of the solution column inside the bushing.

CONDENSER EFFECT

The protective value of a condenser has long been recognized, as high frequency current will enter a condenser quite as freely as it will follow a copper conductor to the ground.

The submerged tube of the Bennett Lightning Arrester functions with a very important condenser action. Tests show that even with the lower end of the tube completely sealed, the Arrester will conduct large currents at high frequency.

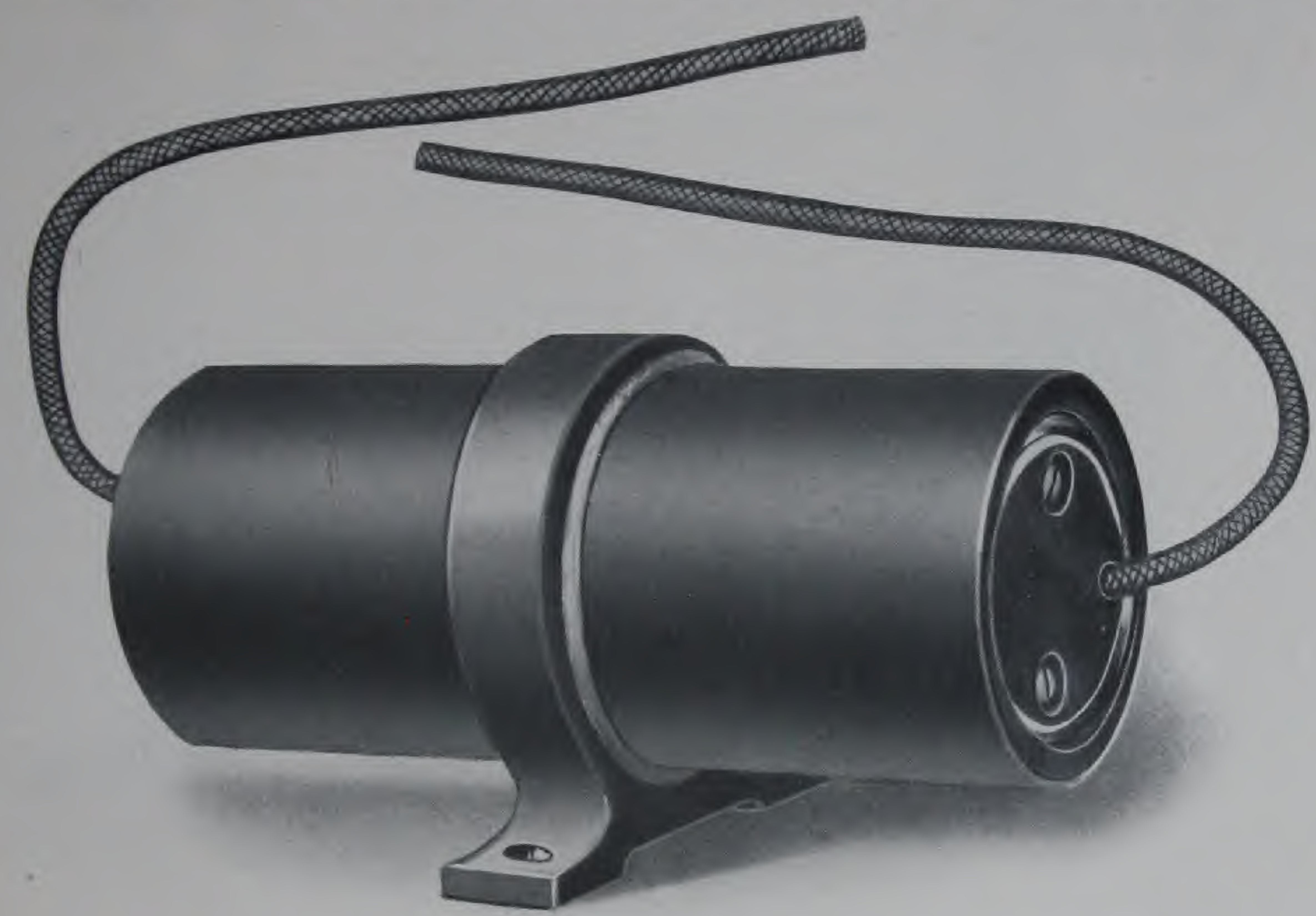
In normal condition, when a high frequency discharge occurs, the Arrester acts like a condenser which is being constantly charged from the line, and which is as constantly discharging through the solution column to ground.

CAPACITY

Bennett Lightning Arresters have a very great capacity for absorbing and dissipating electrical energy. More heat is required to increase the temperature of water than any other substance, and the efficiency of the Bennett Lightning Arrester is largely due to the fact that it contains a large amount of water solution, this solution serving not only to keep the bushing cold, but to absorb the energy of electrical discharges.

Type F-23

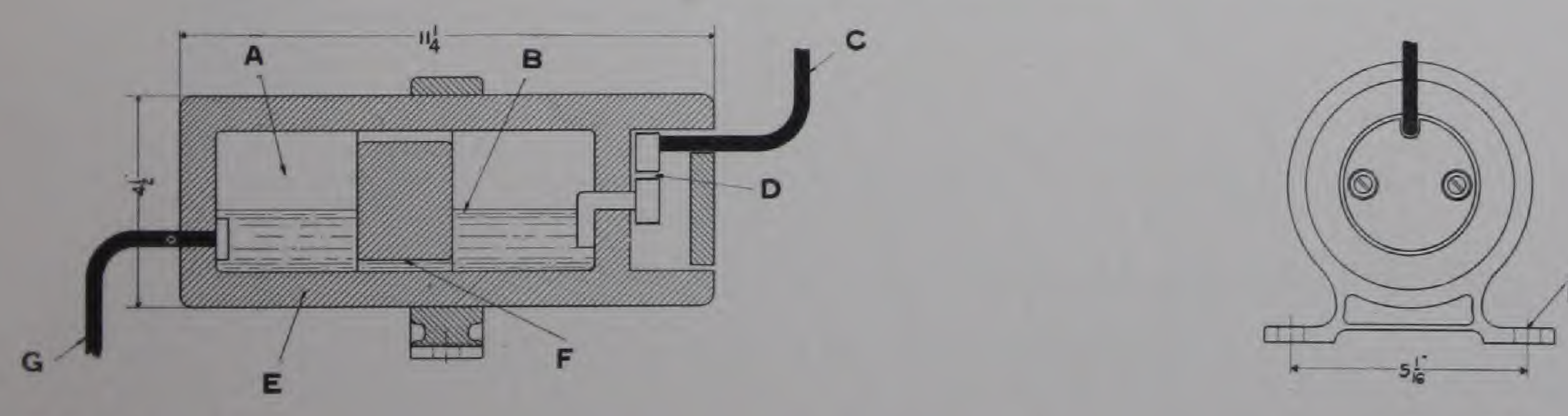
For A. C. or D. C. Service from 600 Volts to 4,000 Volts



Adapted especially to pole-top service or other distribution work. This type, like all other types of Bennett Compensated Disc Lightning Arresters, utilizes the great capacity of water to absorb energy. Due to the water path to ground, a remarkably free passage is given to high-frequency discharges. Entirely self-contained and may be mounted at any convenient point. The water solution is non-freezing. Highly recommended for street railway service.

List Price, $20.00

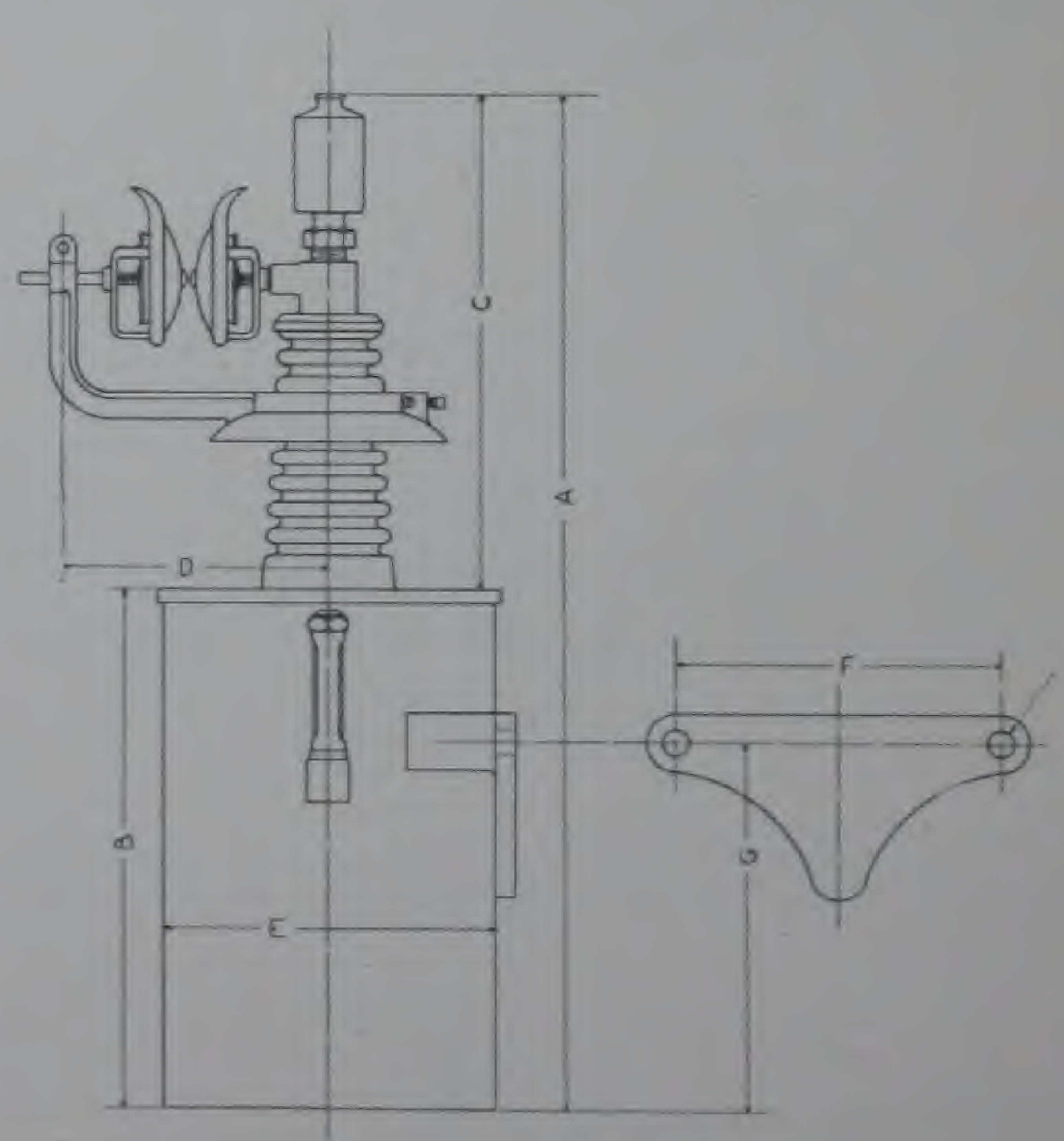
A—Air Cushion *B*—Water Solution *C*—Line *D*—Adjustable Arc Gap
E—Heavy Porcelain Body *F*—Self-Renewing Fuse of Water *G*—Ground



Type D-7

For 2,200 to 4,400 Volts

This type is specially designed for the protection of railroad signal circuits, where an arrester having small dynamic current discharge is desirable.



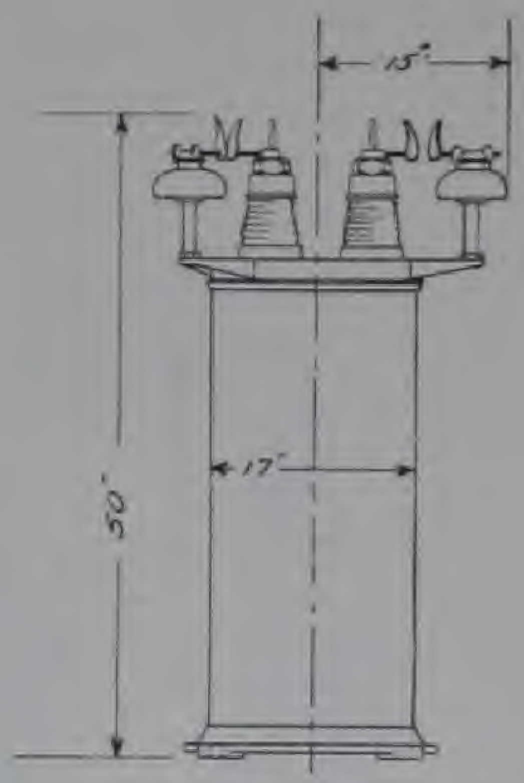
TYPE	VOLTAGE	DIMENSIONS IN INCHES							APPROX LBS.‡		List Price
		A	B	C	D	E	F	G	★Net	Boxed	
D-7	2200-4400	21½	12	9½	5½	6	6¾	12½	★40	70	$41.25

‡Price and Weights are for Single Units with Non-freezing Solution.
★Net Weight Includes Non-Freezing Solution.

Type HH-20

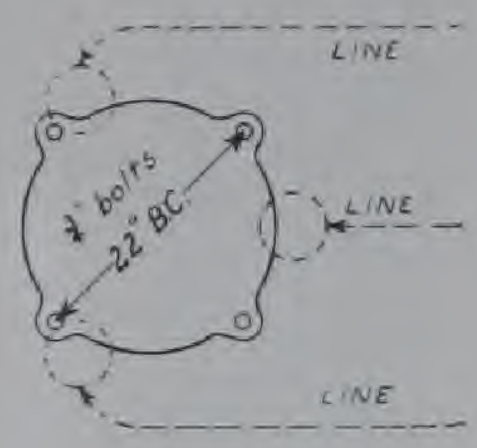
Indoor Service
Types H-20 and HH-20

For 6,600 and 11,000 Volts



Type H-20 is a three-pole unit for indoor service. Has three No. 20 tubes mounted in a single tank with pear-shaped gaps mounted thereon. Recommended where space is limited and heavy surges are involved, as in motor-driven rolling mills, rotary converters, etc.

Type HH-20 is the same as H-20 except that tanks are equipped with heating elements.



Type HH-20

Type D-20

Outdoor and Indoor Service
Type D-20

For 6,600 and 11,000 Volts

Type D-20 is suitable for outdoor and indoor service and is particularly suitable for distribution systems, station busses and steel mills. For outdoor service,this type is equipped with bushing similar to that illustrated on page 18, Type D-24.

For price and dimensions of Type D-20, see page 19.

TYPE	VOLTAGE		DIMENSIONS IN INCHES			APPROX. LBS.		List Price
	Delta	Y Grounded	Height	Tank Diam.	Fdtn. B. C.	Boxed	Tanks Filled	
H-20	6,600	11,000	44	15	22	400	600	$380
HH-20	6,600	11,000	50	17	22	450	650	460

Type D-54

Type D and Type E

For Voltages from 6,600 to 80,000

The illustrations shown are of Type D, and represent the range of sizes, being the largest and smallest of this type equipped with Disc Gaps.

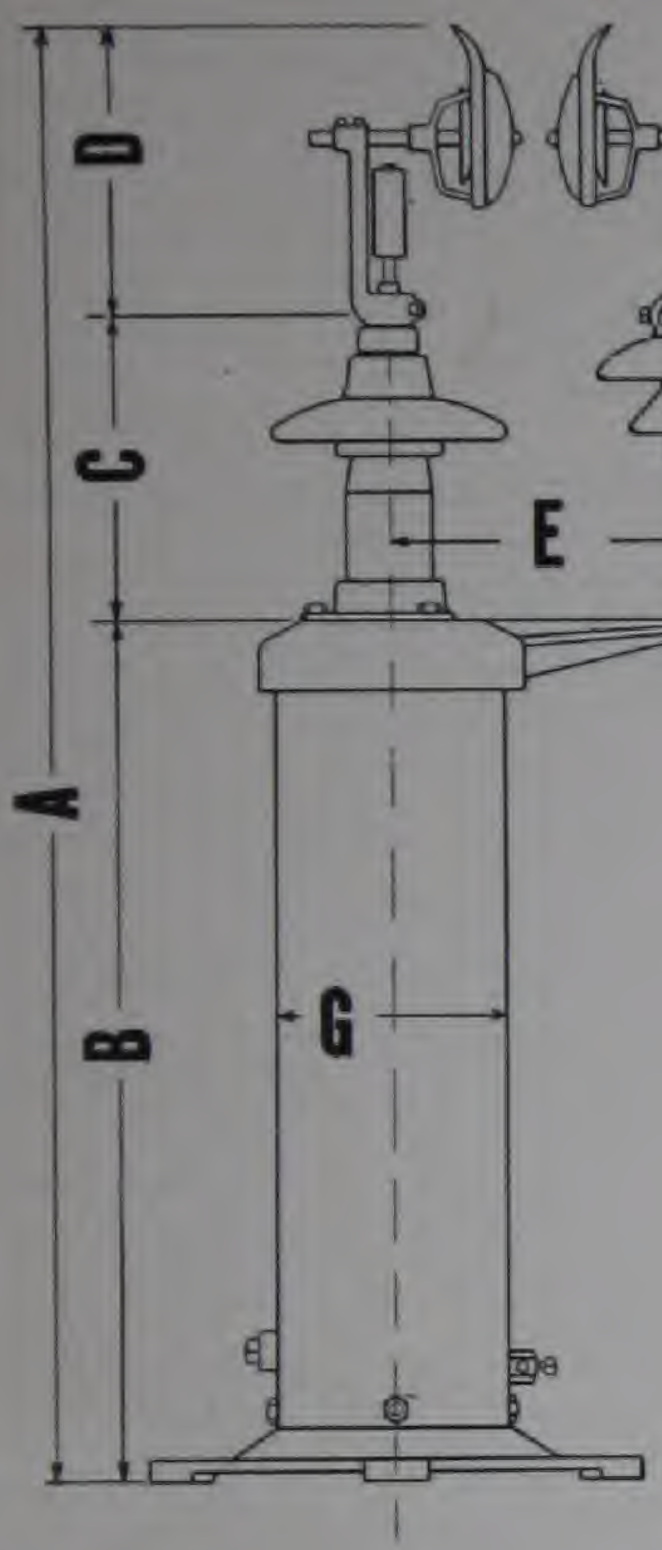
Of the various types of Bennett Lightning Arresters available, all operating on the same basic principle, Type D or Type E will be found to most frequently meet the average engineering requirements.

Type D-24

Type D includes gaps mounted as an integral part of each unit. It is made for many voltages and is the design generally preferred when there is no reason for mounting the gaps on a separate structure.

Type D-20 (illustrated on Page 17) has pear-shaped metal gap terminals. All other units of the D class have Disc Gaps.

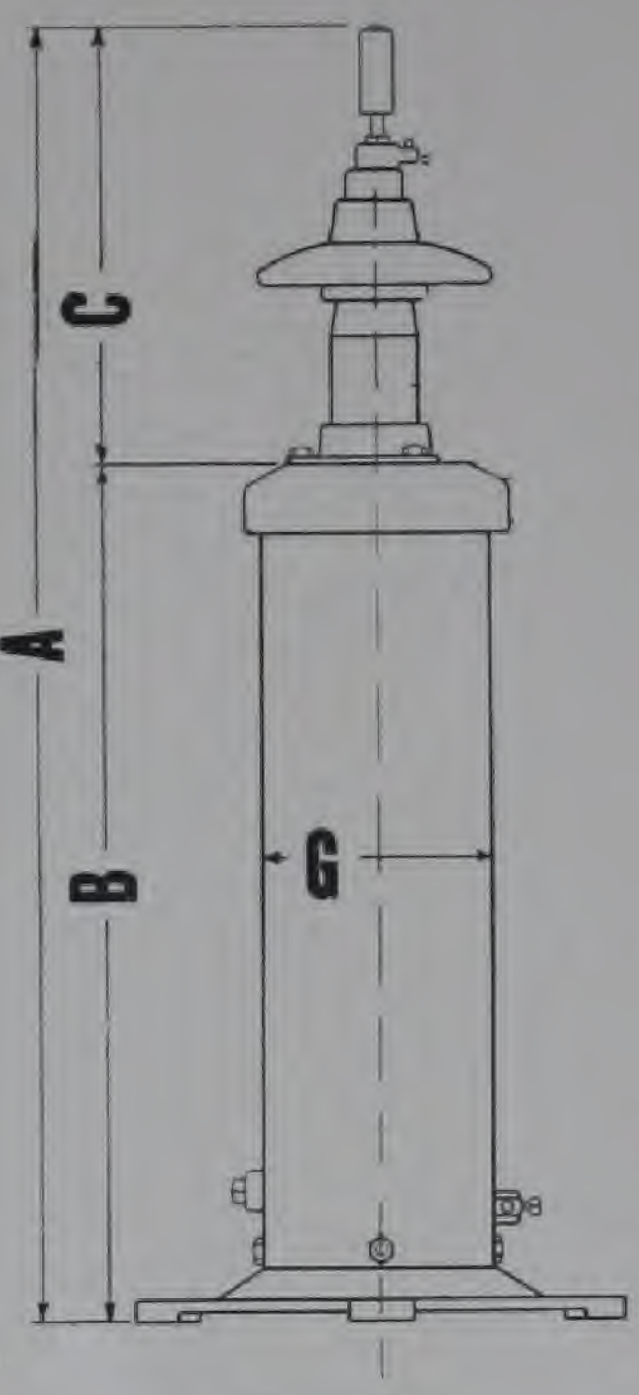
Type E is the same as Type D, but is without gaps. It is suitable for use in connection with gaps mounted on a separate structure in single units or in series, as may be required to meet existing conditions.



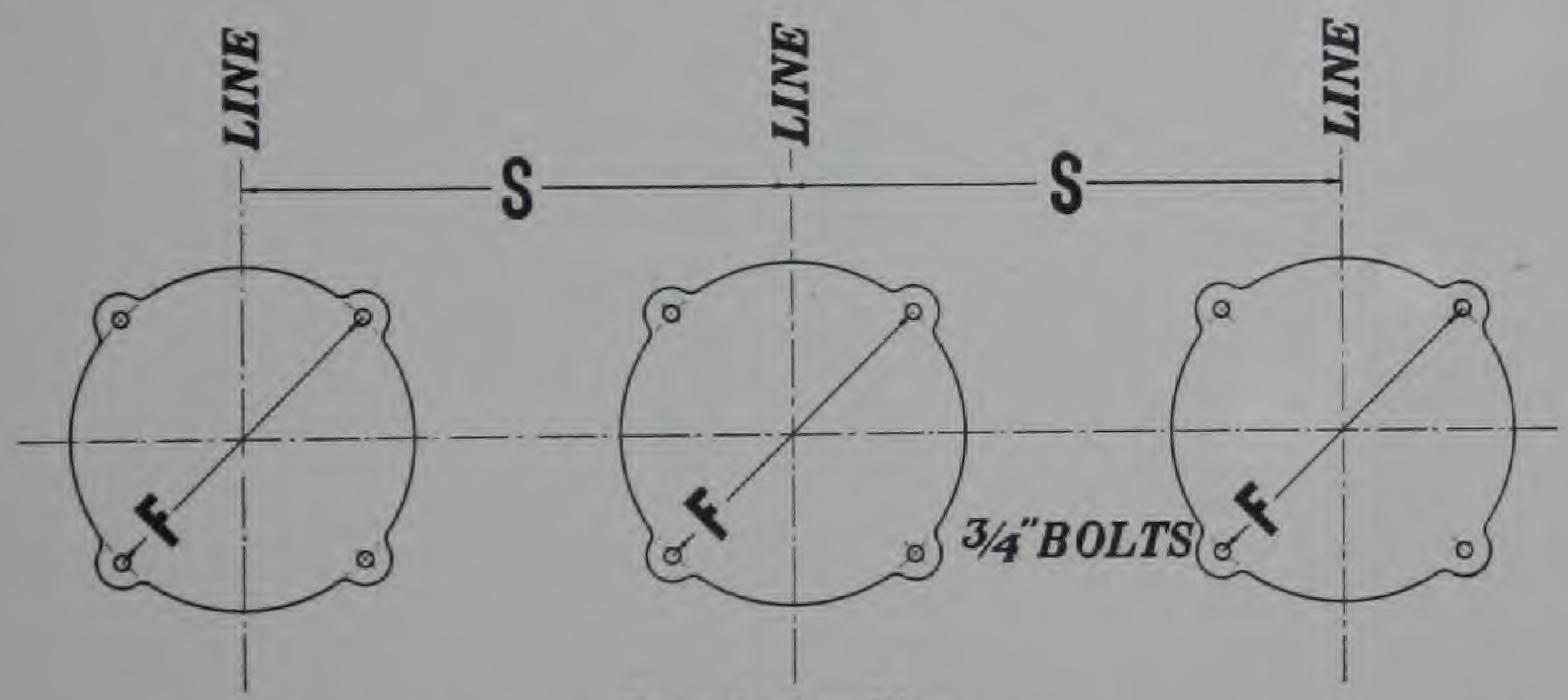
Type D

Type D and Type E

(*Continued*)



Type E



Foundation Plan

TYPE	VOLTAGE		DIMENSIONS IN INCHES								APPROX. LBS.*		LIST* PRICE
	Delta	Y Grounded	A	B	C	D	E	F	G	S	Boxed	Tanks Filled	
D-20	6,600	11,000	44	32	8	4	8	12	8	24	425	575	$360
D-24	15,000	25,000	67	40	14	13	15	20	11	36	750	1,000	748
D-34	25,000	45,000	79	52	14	13	15	20	11	48	900	1,150	968
D-44	35,000	60,000	100	64	18	18	18	22	15	60	1,500	2,400	1,360
D-54	45,000	80,000	112	76	18	18	18	22	15	84	1,800	2,800	1,780
E-24	15,000	25,000	54	40	20	..	..	20	11	36	675	950	$660
E-34	25,000	45,000	66	52	20	..	..	20	11	48	825	1,100	880
E-44	35,000	60,000	82	64	24	..	..	22	15	60	1,350	2,200	1,200
E-54	45,000	80,000	94	76	24	..	..	22	15	84	1,650	2,600	1,600

*Prices and weights are for three-pole sets

Discounts on application

Type DH and Type EH

For Voltages from 6,600 to 80,000

These are the same as Types D and E with Electrical Heating Element Added

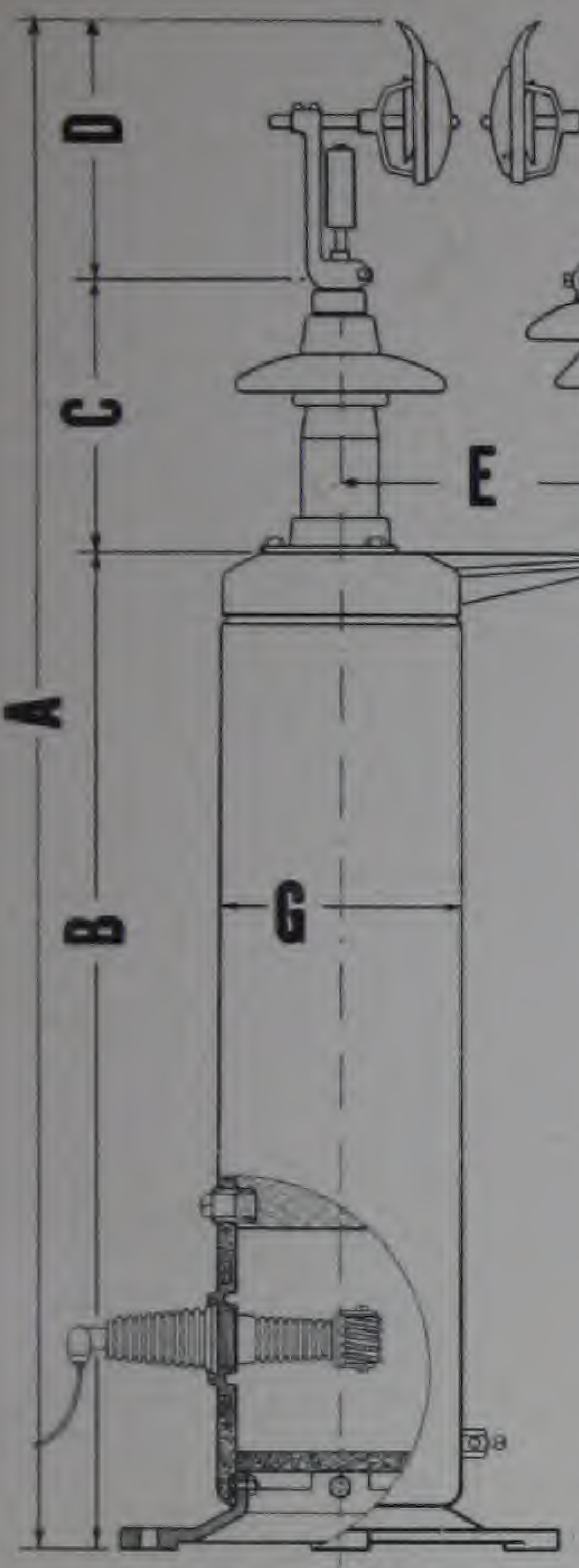
Type DH

Where it is desired to keep Bennett Lightning Arresters in service out of doors throughout the winter, the freezing hazard is usually eliminated by the use of a special non-freezing solution which we can furnish. This solution will prevent damage in temperatures well below zero.

But where exposed installations will be subjected to extremely low temperatures for a protracted period, protection may be assured by a substantial electric heating element. Such an element is incorporated in Types DH and EH.

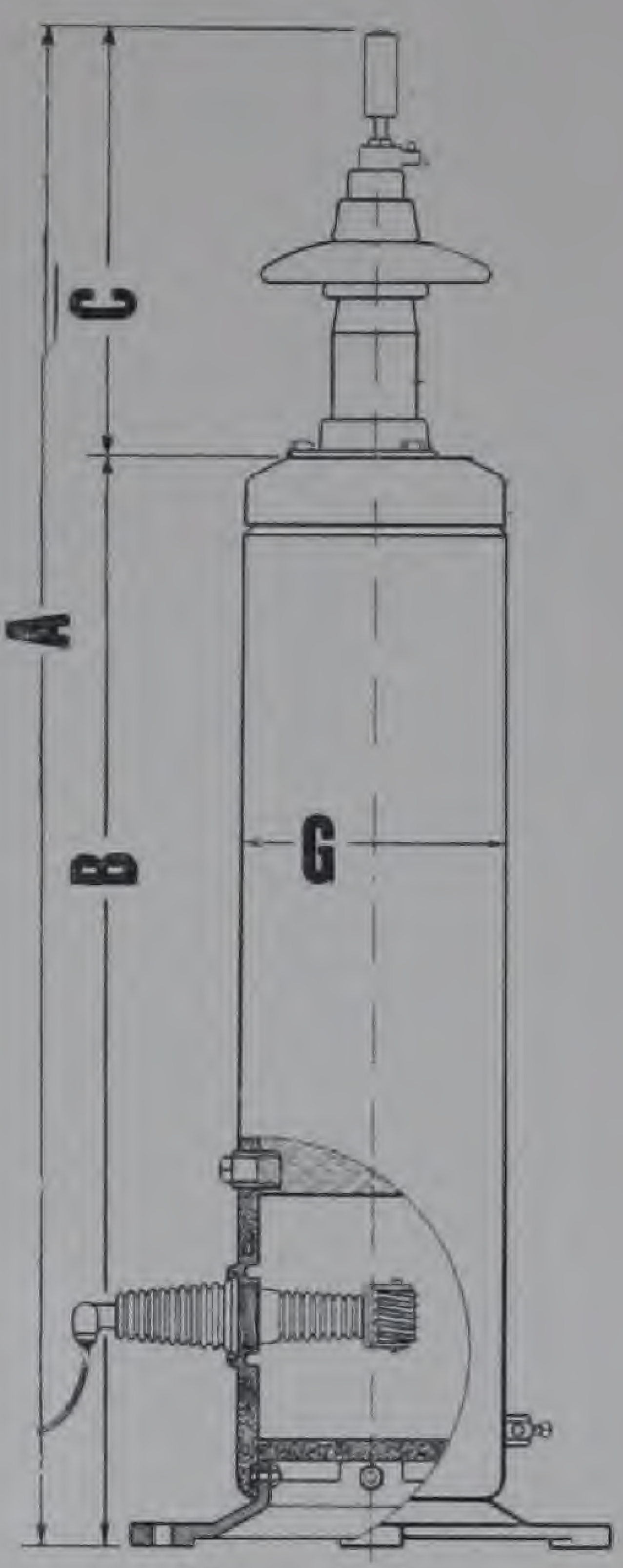
The tanks are lagged with hair felt, covered with rust-resisting Armco iron. The coils are regularly wound for 110 volts, though other windings are provided if required. The heating element is thoroughly insulated from the tank and the entire heating unit is readily removable. Current consumption is negligible.

Type EH is the same as Type DH except that integral gaps are omitted, these to be mounted on a separate structure.

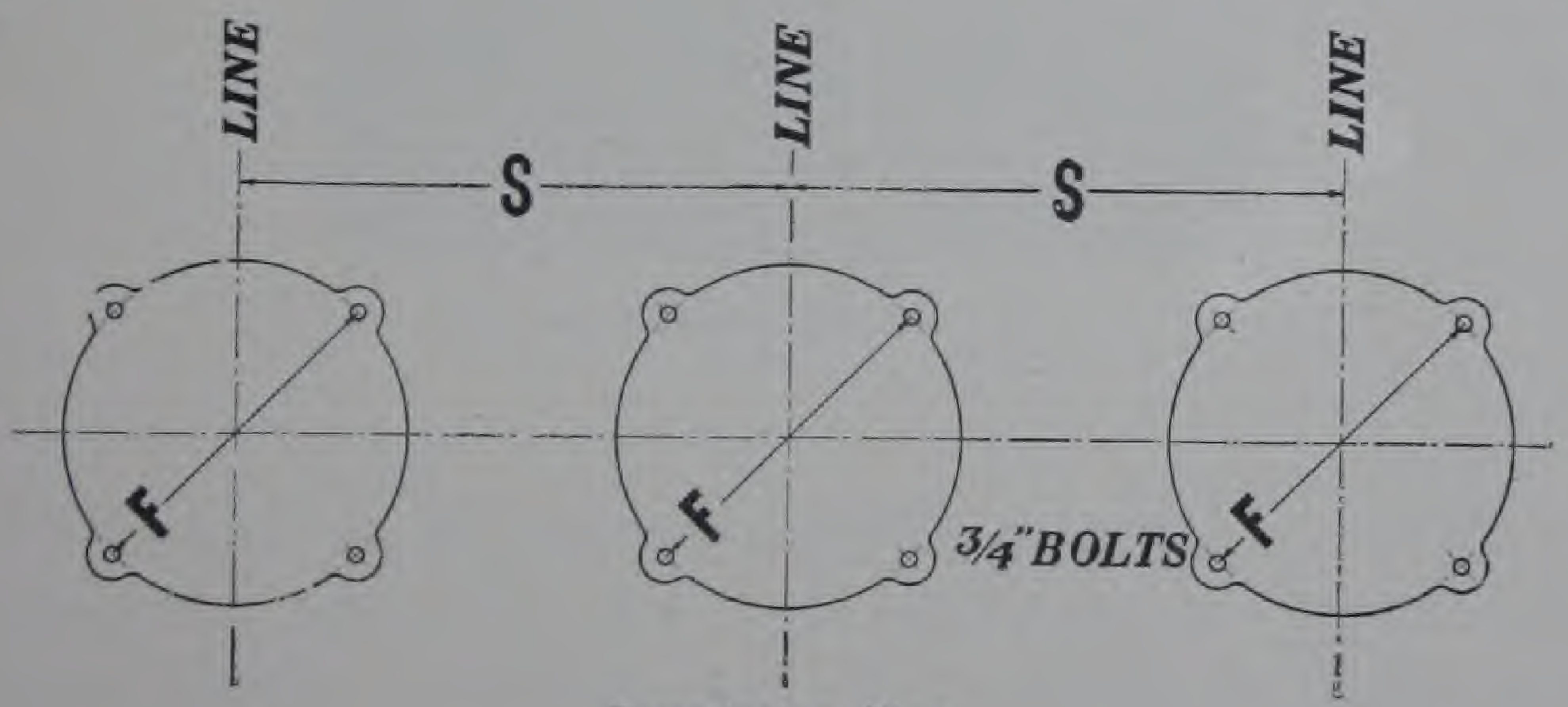


Type DH

Type DH
and
Type EH
(*Continued*)



Type EH



Foundation Plan

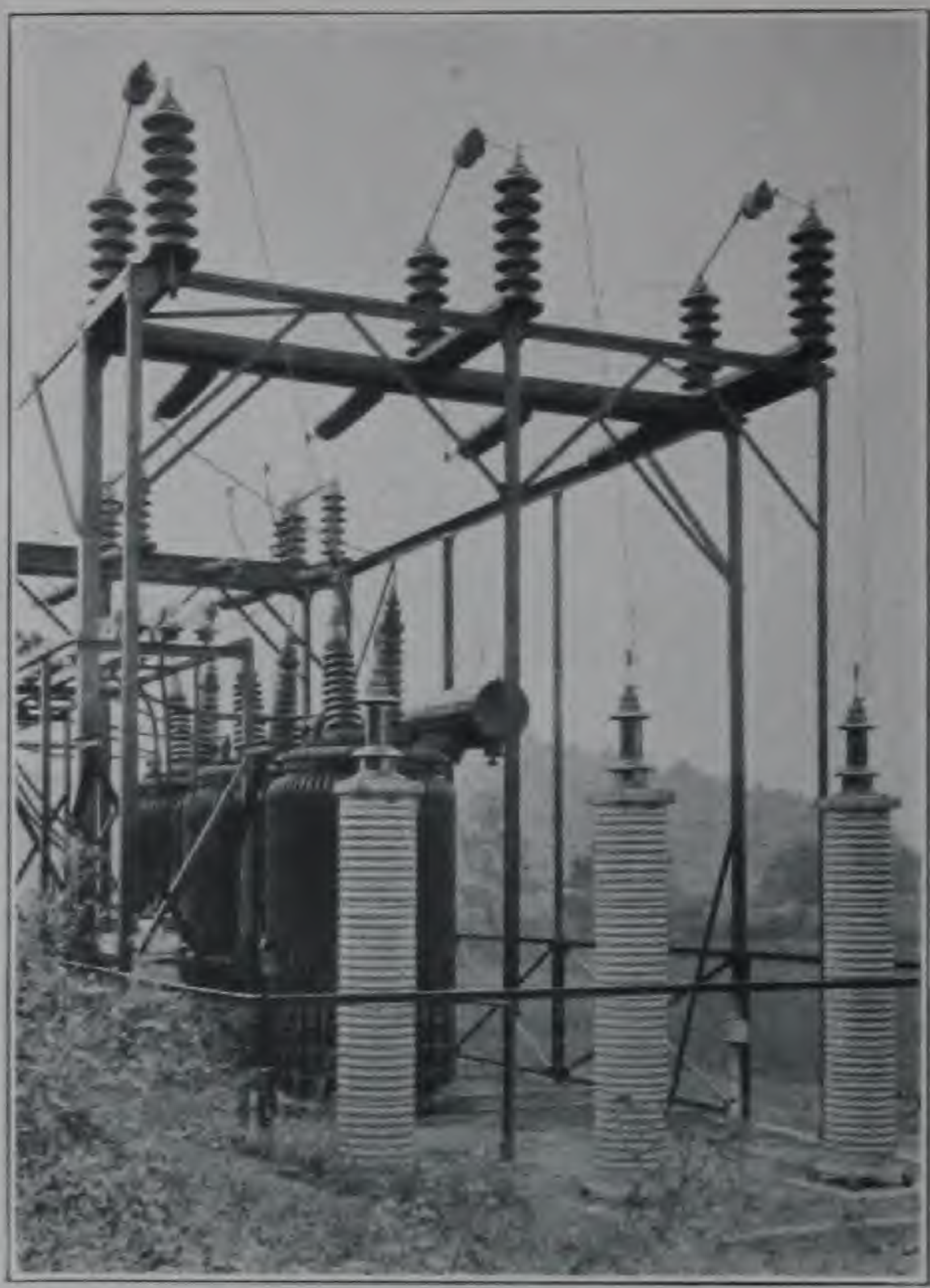
TYPE	VOLTAGE		DIMENSIONS IN INCHES								APPROX. LBS.*		List* Price
	Delta	Y Grounded	A	B	C	D	E	F	G	S	Boxed	Tanks Filled	
DH-24	15,000	25,000	79	52	14	13	15	20	14	36	850	1,130	$828
DH-34	25,000	45,000	91	64	14	13	15	20	14	48	1,050	1,300	1,108
DH-44	35,000	60,000	112	76	18	18	18	22	18	60	1,700	2,560	1,580
DH-54	45,000	80,000	124	88	18	18	18	22	18	84	2,000	2,960	2,020
EH-24	15,000	25,000	66	52	20	..	..	20	14	36	775	1,050	$740
EH-34	25,000	45,000	78	64	20	..	..	20	14	48	975	1,220	1,020
EH-44	35,000	60,000	94	76	24	..	..	22	18	60	1,550	2,460	1,420
EH-54	45,000	80,000	106	88	24	..	..	22	18	84	1,850	2,860	1,860

*Prices and weights are for three-pole sets.

Discounts on application.

Type G-84

For Voltages from 70,000 to 115,000



Type G-84 Installation

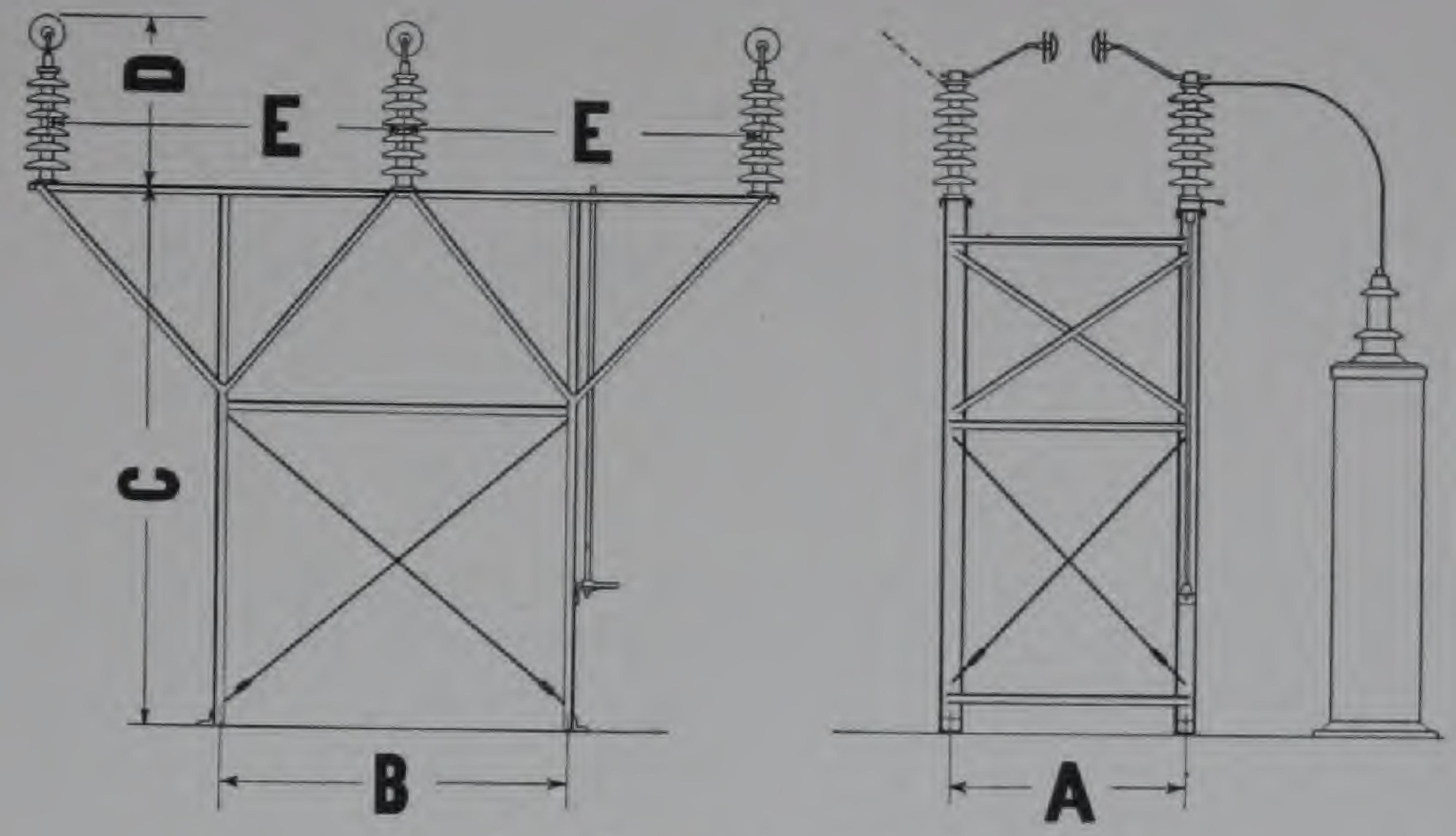
Type G of Bennett Lightning Arresters represents the highest voltage capacity that can be economically incorporated in a single tank. For voltages above 115,000, a cascade arrangement of smaller tanks accomplishes a faster interruption of the arc than would be possible in a single tank larger than Type G-84.

Type G-84 is designed for use with gaps mounted on a separate structure. For this purpose we can furnish a substantial steel frame and six-post type insulators.

If the steel frames and post-type insulators are not desired, we furnish the gaps attached to fittings suitable for whatever post-type insulator the customer uses.

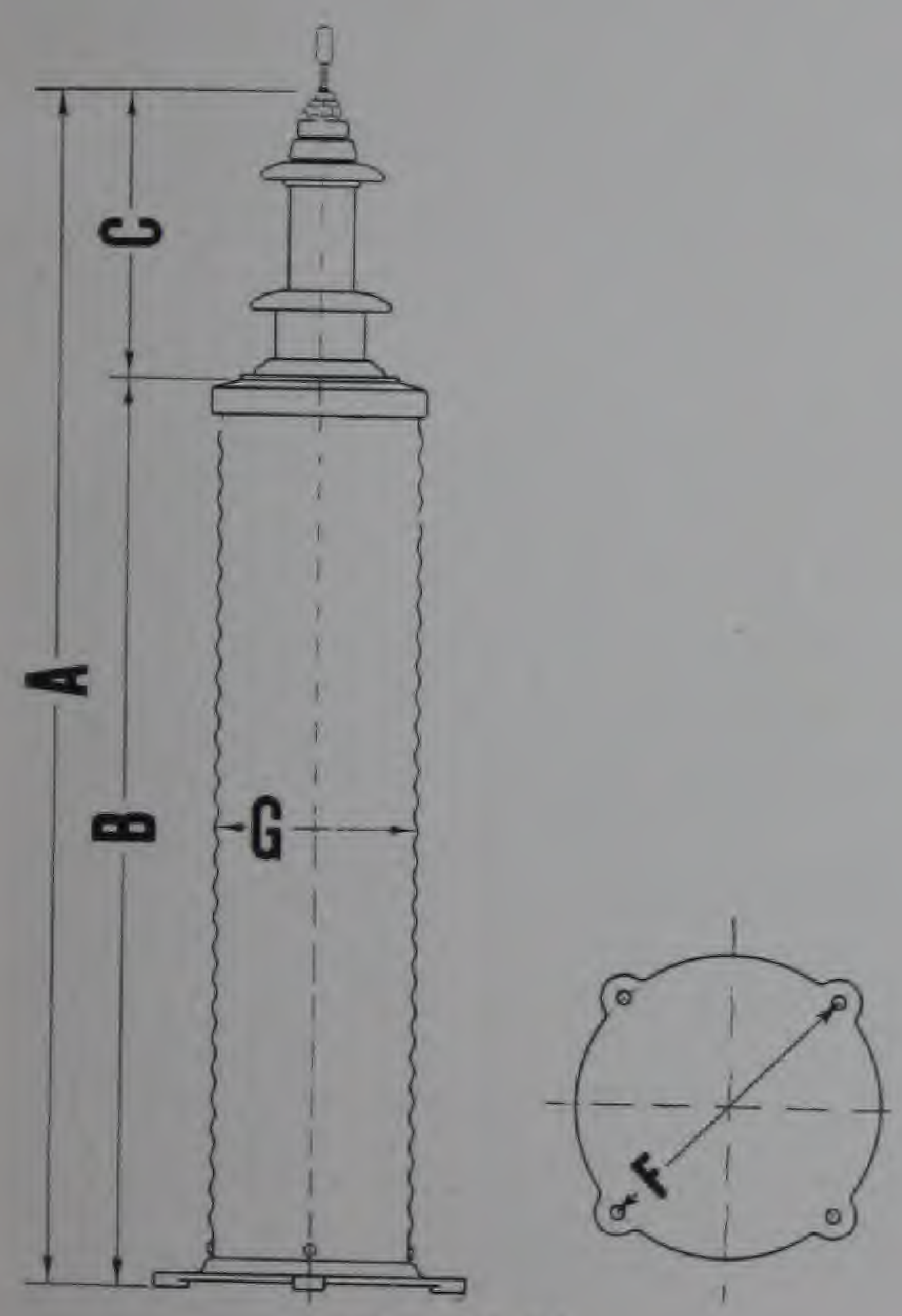
Type GH-84 is the same as Type G-84 with the addition of electric heating equipment.

Type G-84—*Continued*



Steel Support for Disc Gaps

TYPE	DIMENSIONS IN FEET				
	A	B	C	D	E
G-84	6′	10′	14′	4′	10′



Type G-84

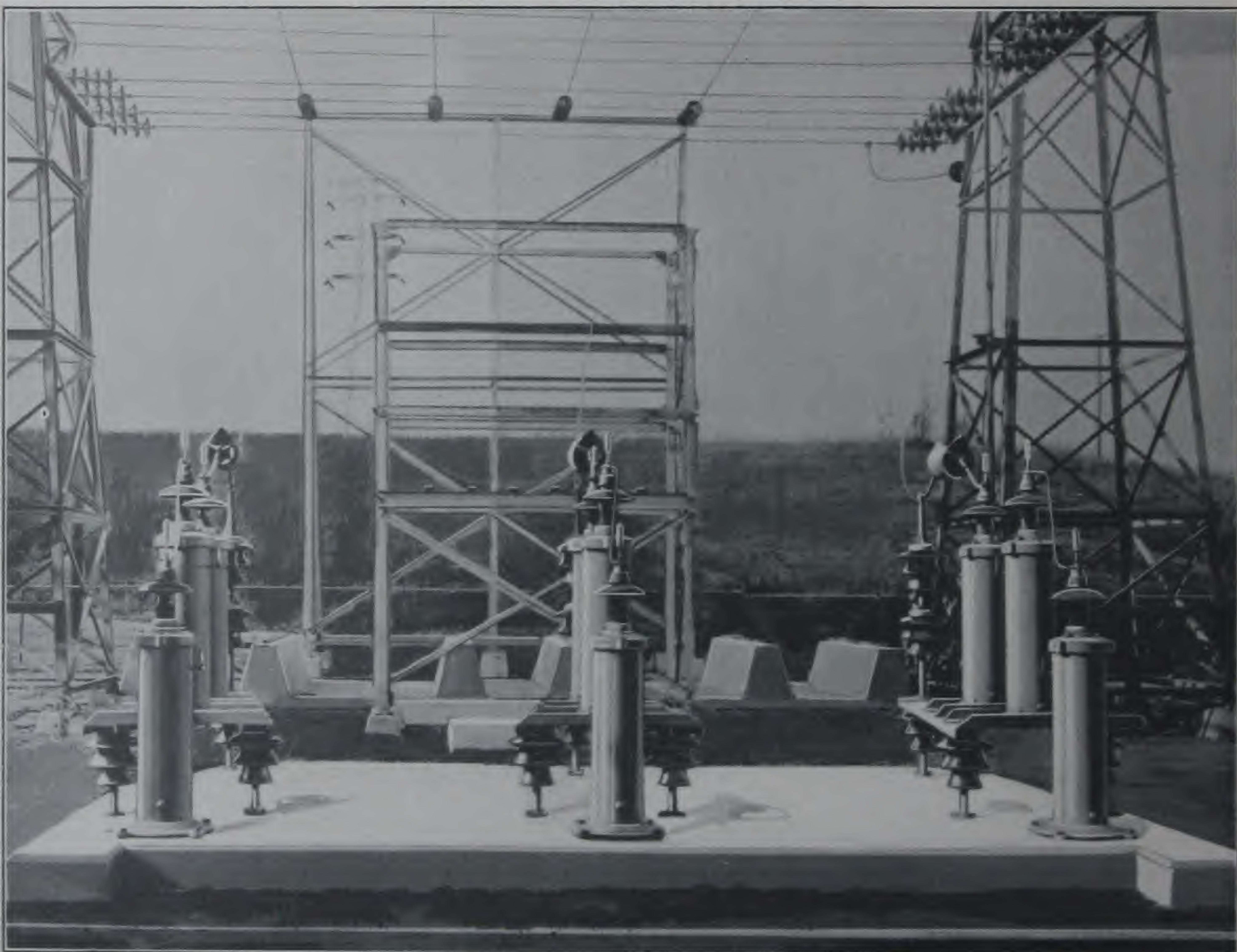
TYPE	KILOVOLTS		DIMENSIONS IN INCHES					APPROX. LBS.★		LIST PRICES	
	Delta	Y Grounded	A	B	C	F	G	Boxed	Tanks Filled	★	Complete
G-84	70	115	138	108	30	28	20	4,750	5,350	$3,940	$5,200
GH-84	70	115	156	126	30	28	24	5,400	6,000	4,720	5,980

★Without steel frame and post-type insulators.
Prices and weights are for three-pole sets.
Discounts on application.

Type CE

A Cascade Arrangement Recommended for the High Voltages

For 66,000 to 220,000 Volts



A Typical Type CE Installation Employing Cascade of Three Units Connected in Series

Type CE—*Continued*

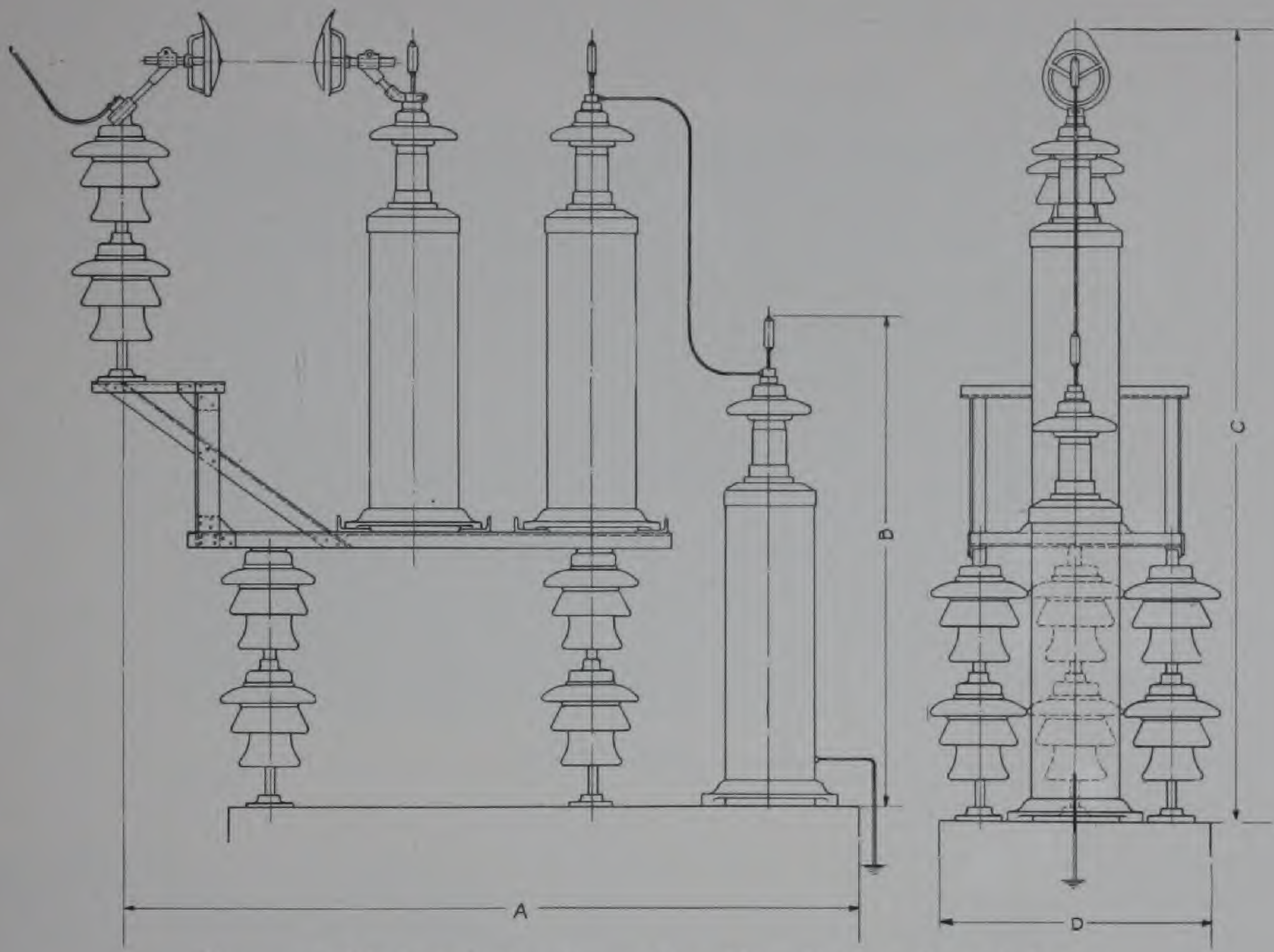


Diagram of CE Installation, Comprising Three Units in Cascade Series; also End Elevation of Same

Technically, it would be quite possible to build a single-tank Bennett Lightning Arrester of sufficient capacity for use on systems involving voltages higher than 115,000.

But in practical operation, it has been found that on systems of 115,000 volts and above, it is desirable to replace the single large unit with a plurality of smaller units, connected in series and mounted in cascade.

Advantages are: the smaller units are more easily handled, there is a slightly faster action in interrupting the arc, and the cost is less.

Type CE—*Continued*

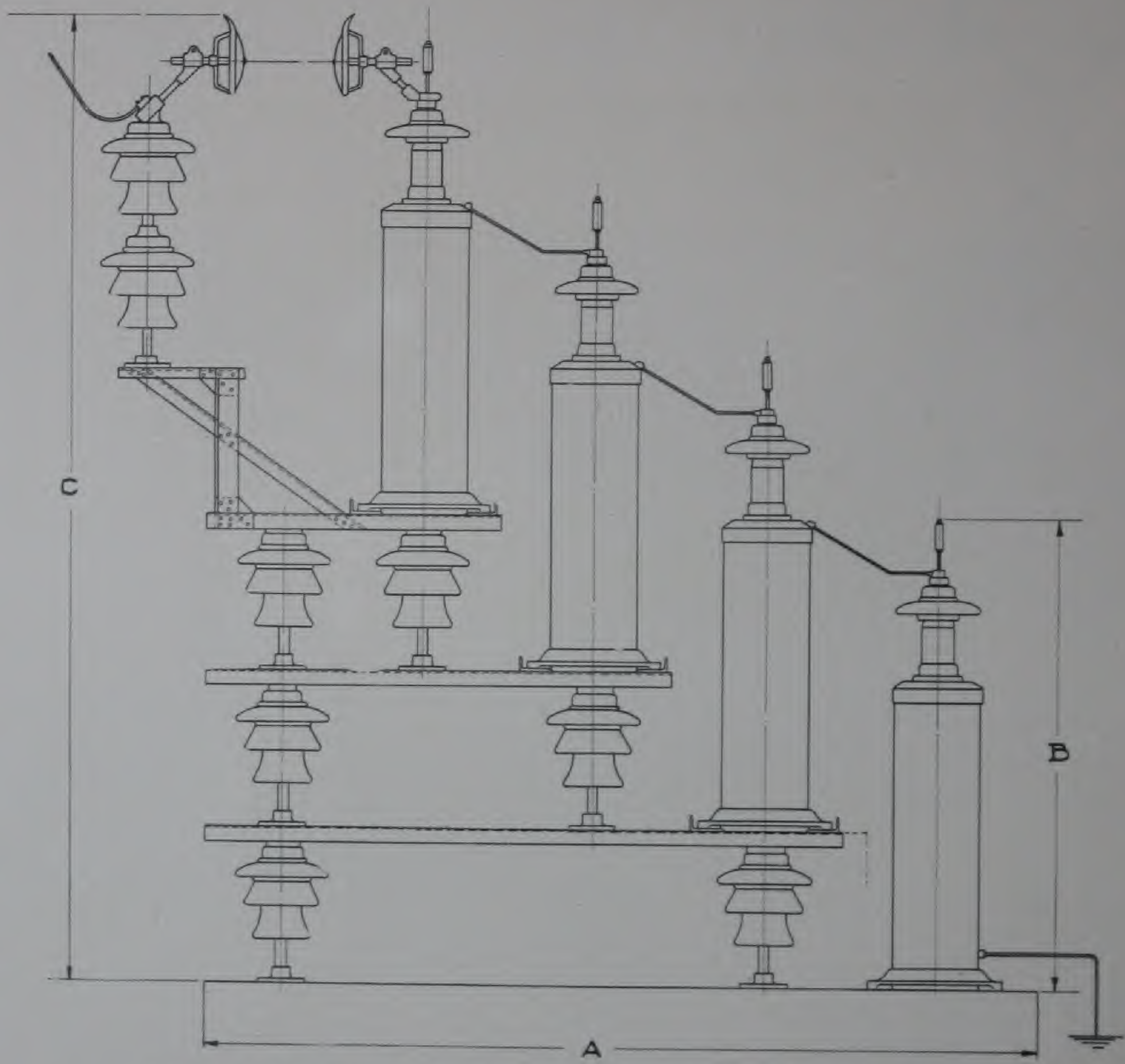


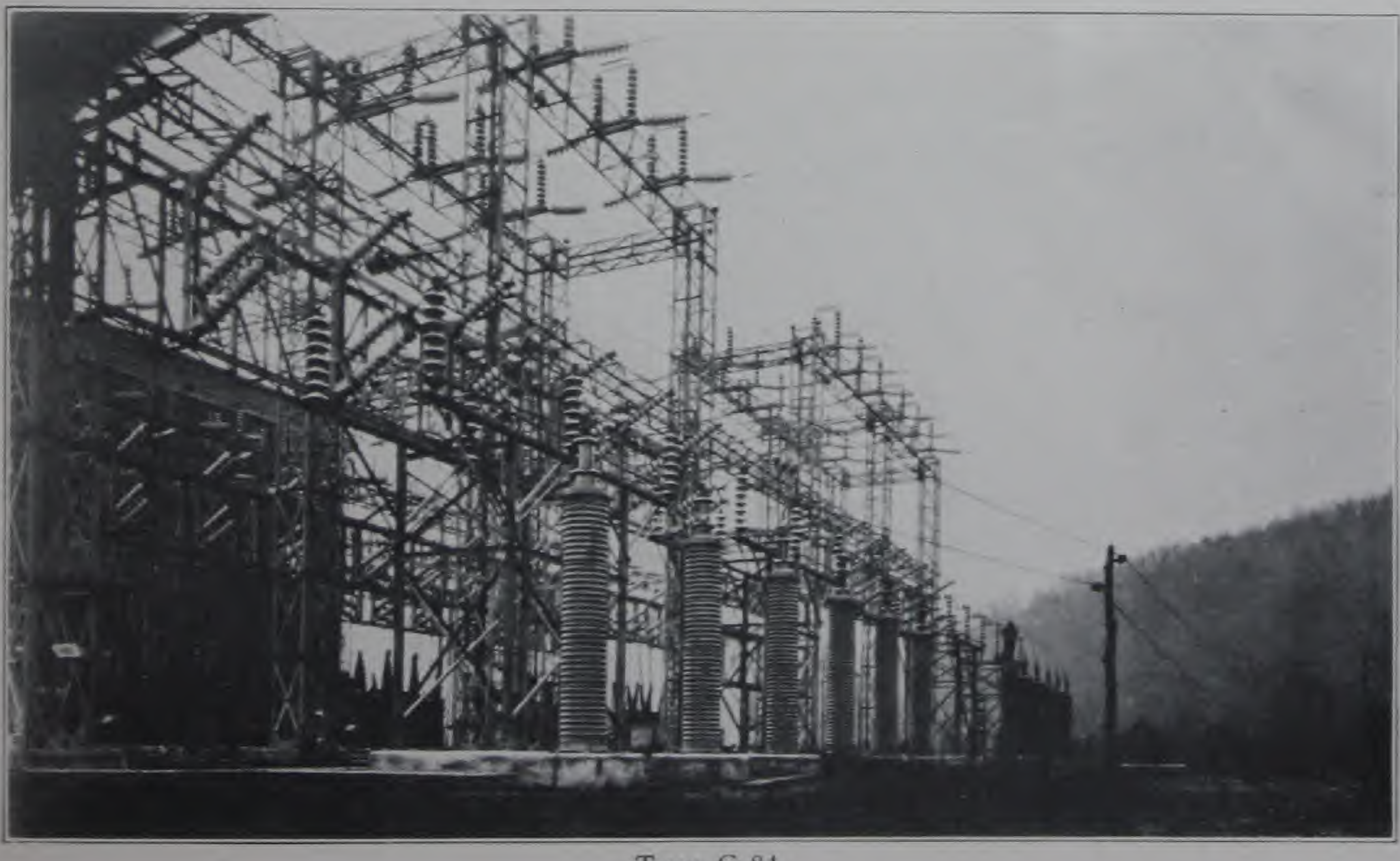
Diagram of CE Installation, Comprising Four Units in Cascade Series

The units comprised in Type CE are standard Type E units, connected in series and insulated from each other.

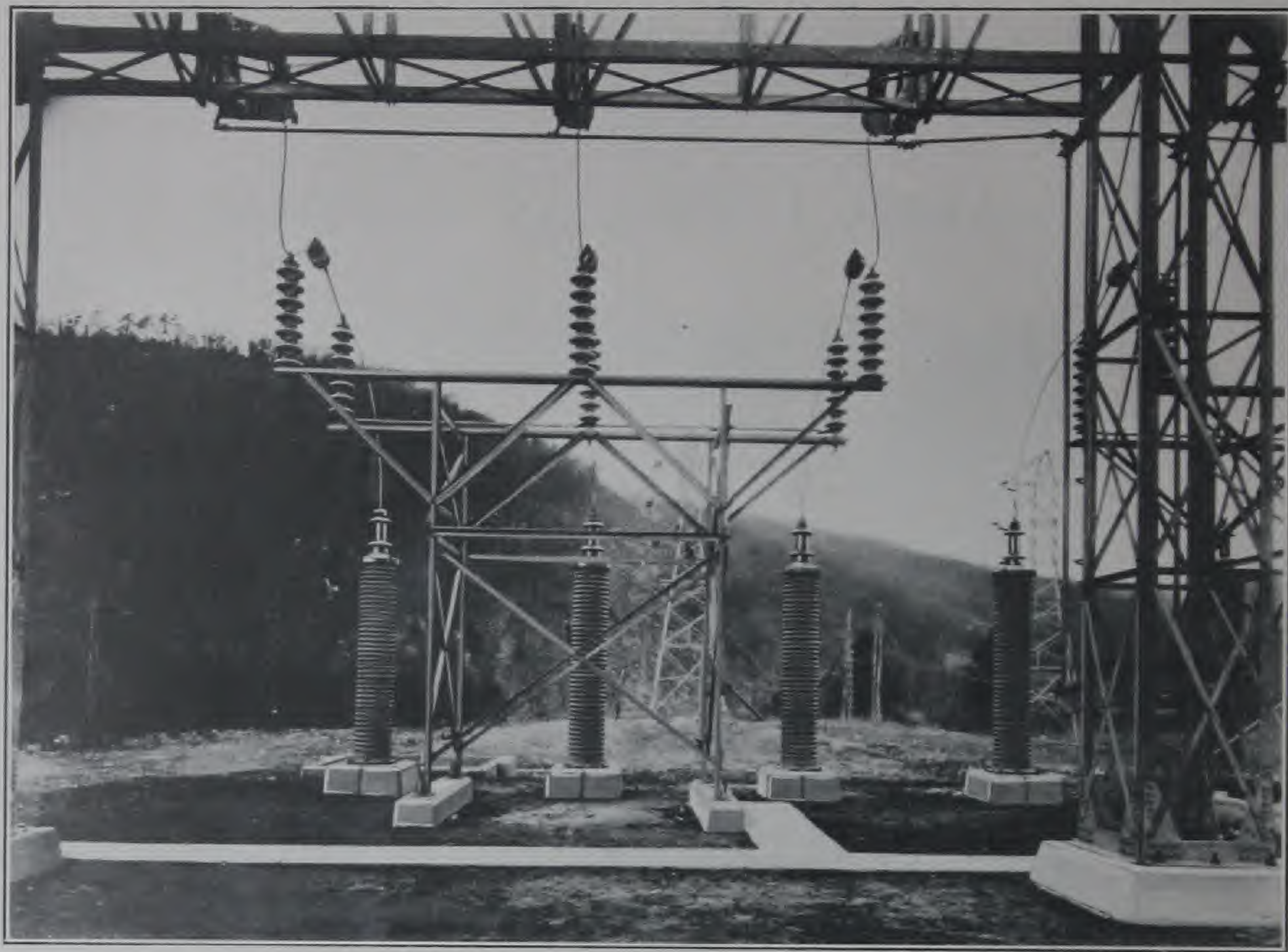
Special data covering dimensions, capacities, weights and prices of Type CE equipment will be furnished on request.

Typical Installation
of the
Bennett Lightning Arrester

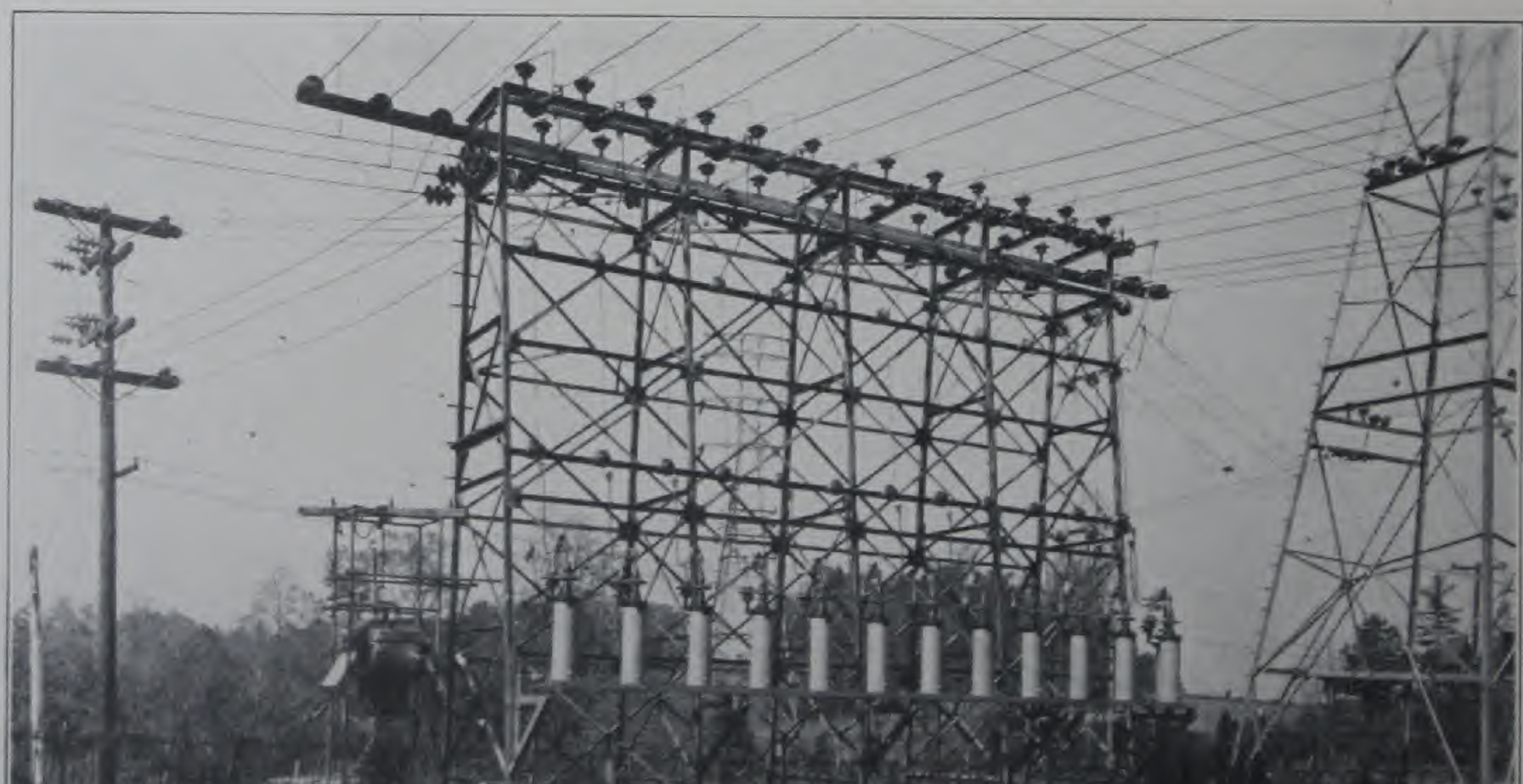
Type D-34



Type G-84

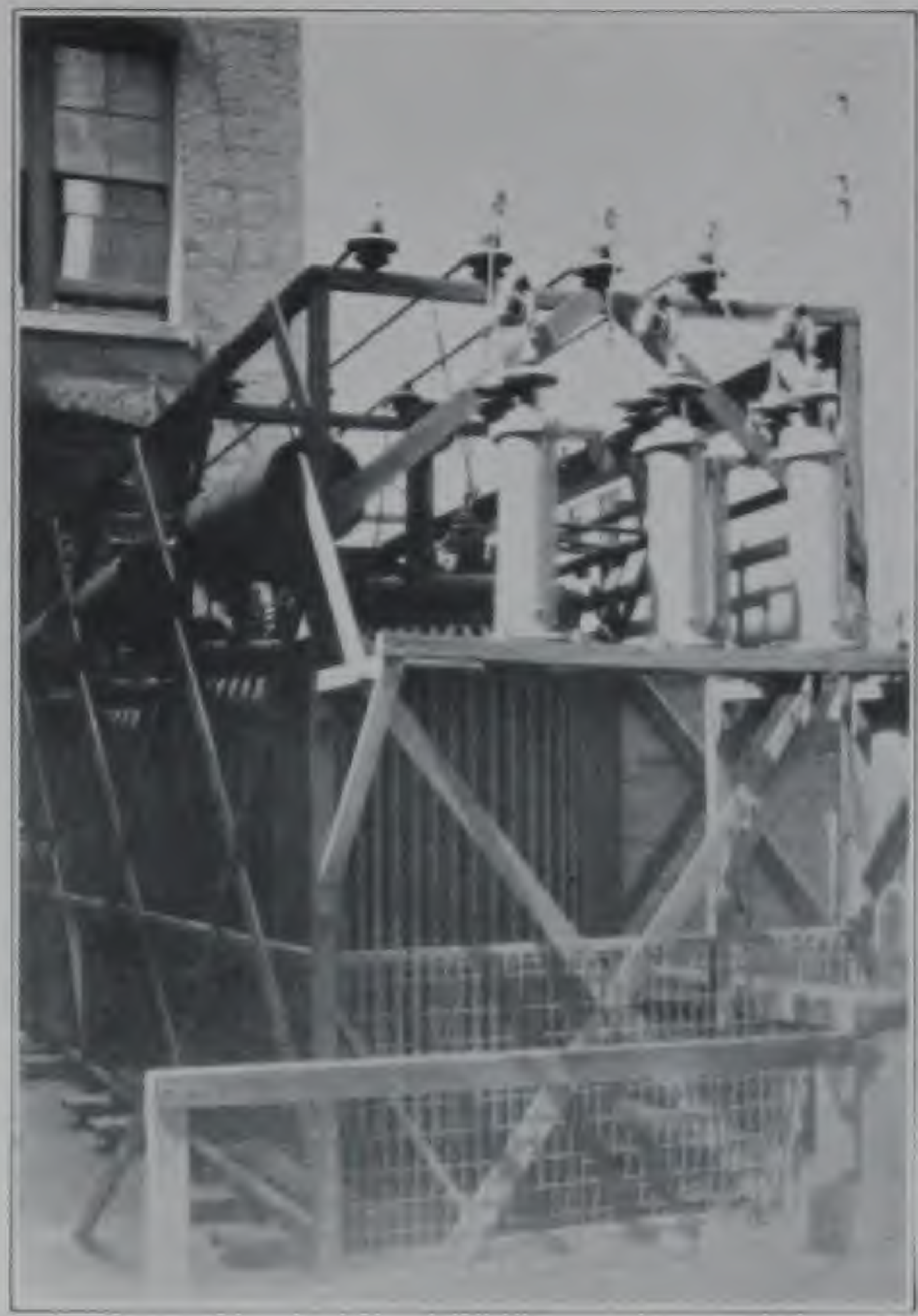


Type G-84

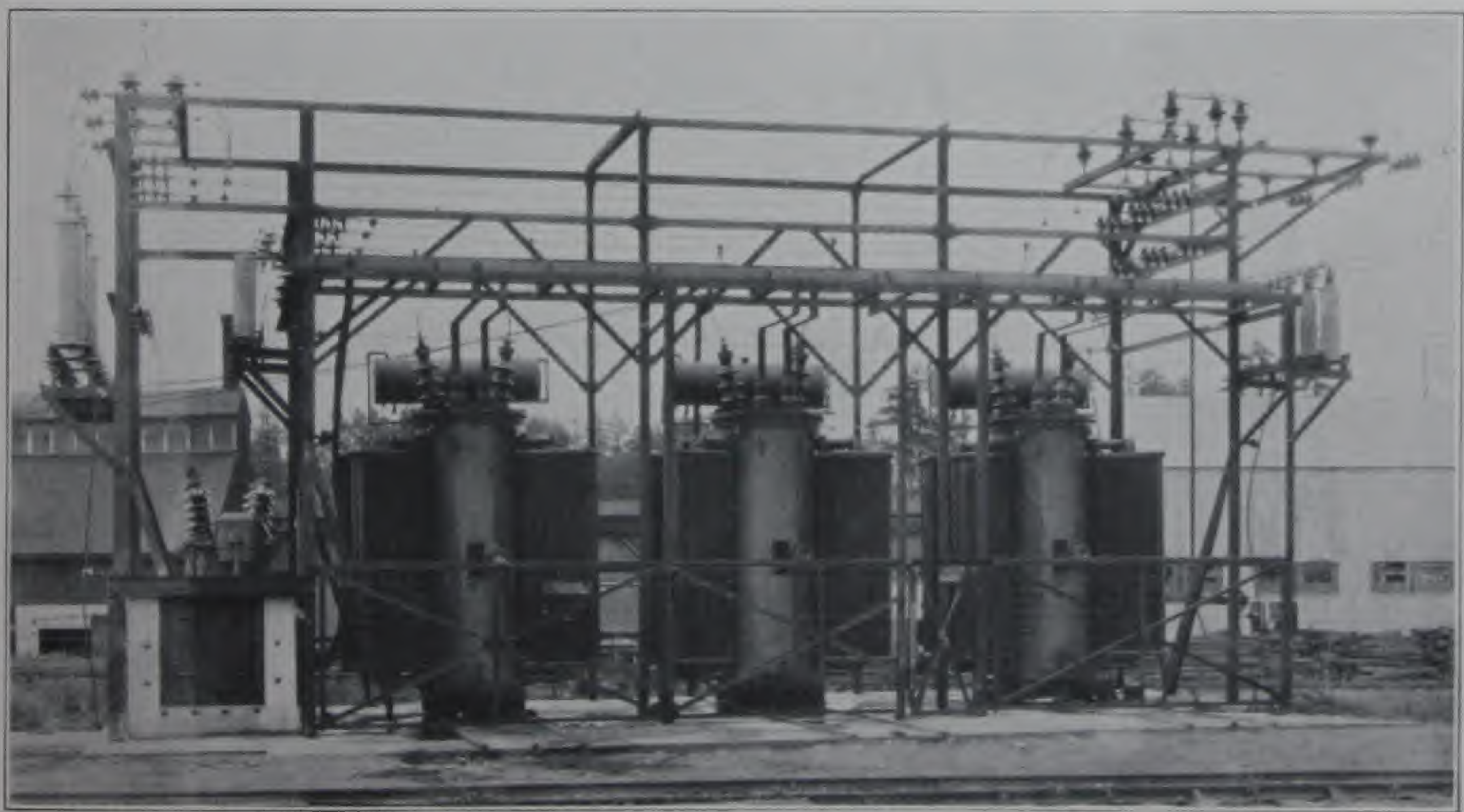


Type D-34

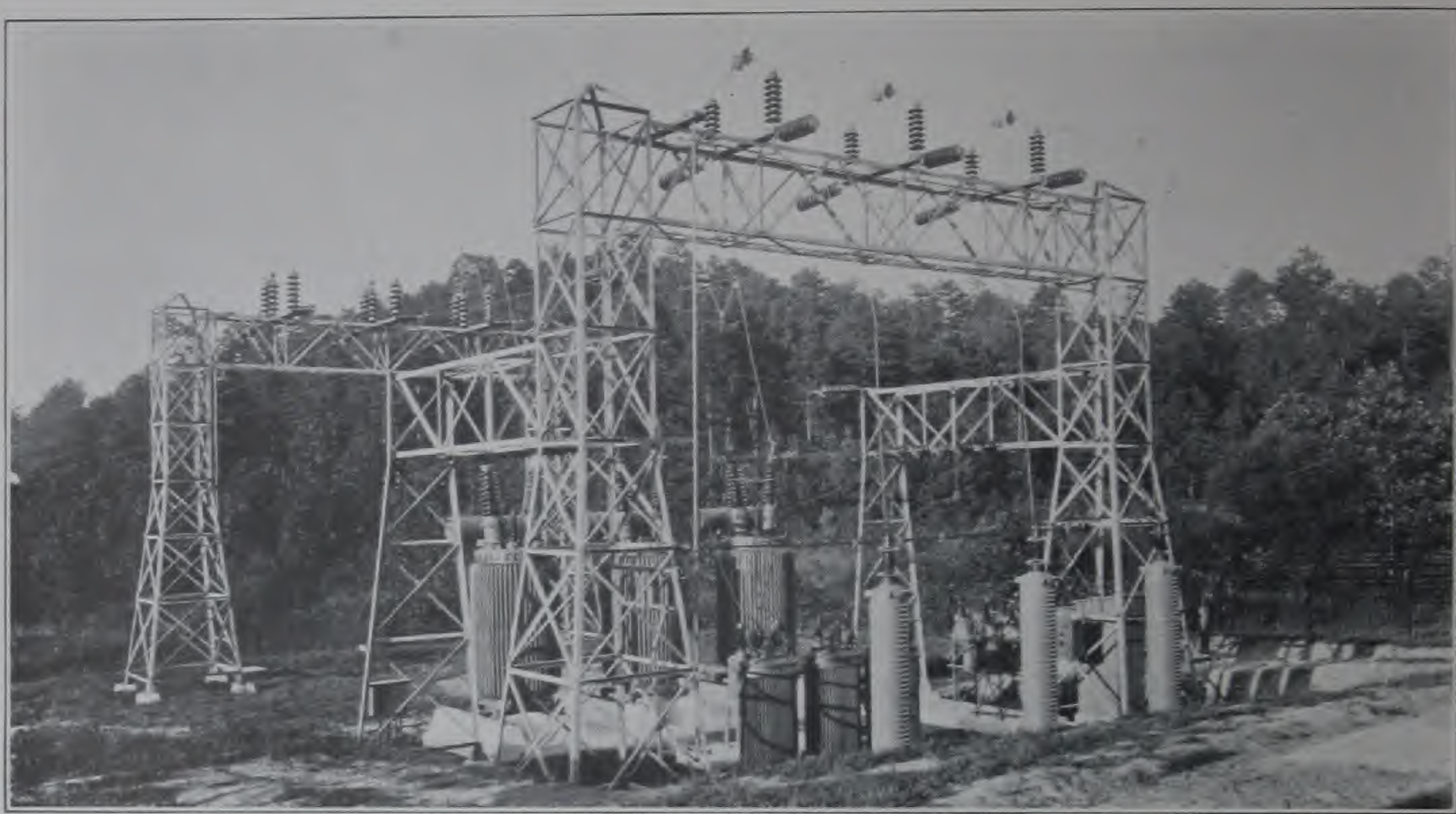
Type G-84



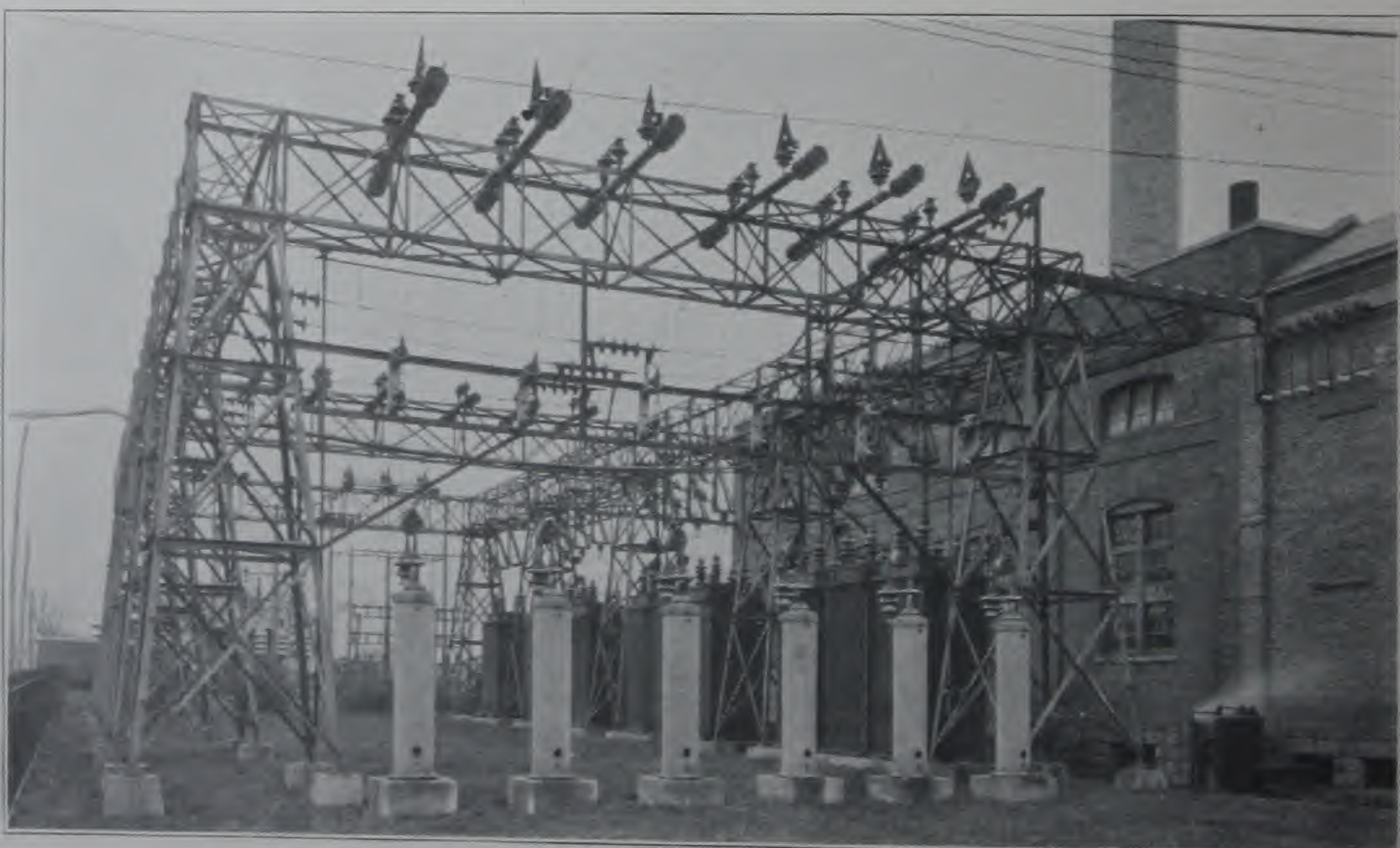
Type D-24



Type D-34



Type G-84—110,000 Volts



Type DH-44—35,000 Volts

Installation

FILLING THE TANKS: Tanks are to be filled with water having a somewhat greater conductivity than rain water. The water supplied by many city systems is suitable without the addition of any salt. Water from mountain streams generally requires a little salt. Rain water is similar to mountain water. Fill the tanks so that the water level is at the center of the gauge glass when the bushing is in position. The drain plug at the bottom of the tank and the filling plug in the cover make it easy to adjust the water level. Never add salt until after testing. See page 32.

SETTING THE ELECTRODE: The electrodes are made up of half-inch round carbon rods securely held in brass clamps. The standard arc lamp carbon can be used when replacing any that may become broken, and it is advisable to point the electrode, though this is not necessary.

The arrester functions properly over a wide range of adjustment of the electrodes, but the best action and the quickest operation are secured when the electrode tip is just submerged, as shown in Figure 6. The setting is easily checked by removing the bushing cap and electrode together. Proper adjustment will show about $\frac{1}{4}$-inch of the tip of the electrode wet. If the electrode is slightly above the water the equipment will still function, although the additional gap between the electrode and the water slightly increases the arc-over voltage.

The packing nut holds the electrode rod in position and also secures a tight joint through the bushing cap. This keeps a better cushion of air in the upper part of the bushing. The breather equalizes the water level inside the bushing, and at the same time limits the escape of water vapor.

ARC GAPS: Adjust the gaps according to the following schedule:

6,600 indoor	Pear Gap	$^3/_{16}$-inch
6,600 outdoor	Pear Gap	$\frac{1}{4}$-inch
13,200	6-inch Discs	$^{11}/_{32}$-inch
22,000	6-inch Discs	$^{41}/_{64}$-inch
33,000	8-inch Discs	$^{55}/_{64}$-inch
44,000	8-inch Discs	1 $^{19}/_{64}$-inch
66,000	8-inch Discs	2 $^{29}/_{64}$-inch
110,000	8-inch Discs	6 $^{39}/_{64}$-inch

The figures given are approximate and may be modified to meet conditions on different systems, especially with respect to altitude. For each thousand feet above sea level it is customary to increase the gap setting five per cent. The compensating shields are regularly set at the proper place before the Disc Units are shipped from the factory. If for any reason adjustment becomes necessary, set the shield so that it is from $\frac{3}{4}$ to $\frac{7}{8}$ of the entire range of travel back from the Disc itself.

Installation—*Continued*

Ground Connections: It is necessary to have an effective ground connection and this is obtained by any of the usual methods. Unless provision can be made for burying a metal plate, a very effective way is to drive a galvanized iron pipe as far as possible into the ground. If this can be driven at the bottom of an excavation, greater effectiveness is obtained. Two pipes are often used, one at each end of the arrester installation, connecting these pipes with a 2-0 copper wire and connecting the three arrester tanks to this ground bus.

It is not best to use the steel framework of a substation as ground connection for any lightning arrester. This tends to impose high voltage on the entire framework in case a heavy discharge takes place, and restricts somewhat the functioning of the arrester. When the arrester tanks are supported on a steel framework it is advisable to interpose an insulated platform, running a special ground wire for the Arresters and also having the steel framework positively grounded separately. *On all ground wires sharp corners should be avoided and connections should be as nearly straight as possible.*

Testing: After tanks are filled, gaps and electrodes set and ground connections made, connect one unit to the line. Then touch the head of a switch stick across the arc gap. If the arc cannot be established across the gap, but merely makes a small discharge while the switch stick is there, add some table salt. (NaCl.)

A convenient way is to make a few quarts of saturated salt solution and after the extra salt has settled to the bottom of the vessel, use a cup or glass to measure the amount of salt solution added to each tank. For the D-20, one or two tablespoonfuls of solution is sufficient to add to one tank at a time. For the D-24's a half glass of salt water can be added at a time. The arresters with 15-inch tanks may have a glassful of salt water added each time. In every case the solution must be thoroughly mixed with the water *in the tube*, as well as that in the tanks, and a test made before any additional salt water is added. Never add undissolved salt to the tank, as some of this settles to the bottom and later when it dissolves it changes the conductivity of the solution. It is convenient to merely pour the salt solution through the filling plug and then blow down through the bushing, forcing all water out of the bushing and in this way stirring the water. Continue to add the salt water in small amounts making tests each time, until an arc can be established across the gap, and the interrupter operates. During severe testing the arc will sometimes rise from a few inches to a foot above the gap before the discharge is interrupted, and at other times it will be extinguished almost instantaneously. This depends on the momentary position of the water in the tube. The arrester provides a path to ground in any case, and can cause no surge on the system even if the arc

Installation—*Continued*

holds for a noticeable period. When the electrode is properly set the arc from a single discharge is snappy and rises not over three or four inches before being extinguished.

After the proper amount of salt solution has been determined for one tank the same amount can be added to each remaining tank without further testing.

Adaptability: Bennett Arresters function properly over such a wide range of adjustment that only the requirements of the operating system need be considered. On systems which are widely extended, with a correspondingly great electrostatic capacity, a solution may be used which has a greater conductivity than would be advisable on a smaller system where the line circuit breakers would be opened by a discharge which would not affect a heavier line.

The sort of surge which causes most destruction is the thin static spark which has very high voltage but small current. The Bennett Arresters will relieve this sort of surge even when pure rain water is in the tanks, and they become still more effective as the water conductivity is increased.

The only objection to very heavy discharges at line voltage is the possibility that such a discharge may operate the station switches, thereby interrupting service temporarily. It is found that a solution proportioned to give discharges of between 10 and 50 KVA at line voltage is suited to average operating conditions.

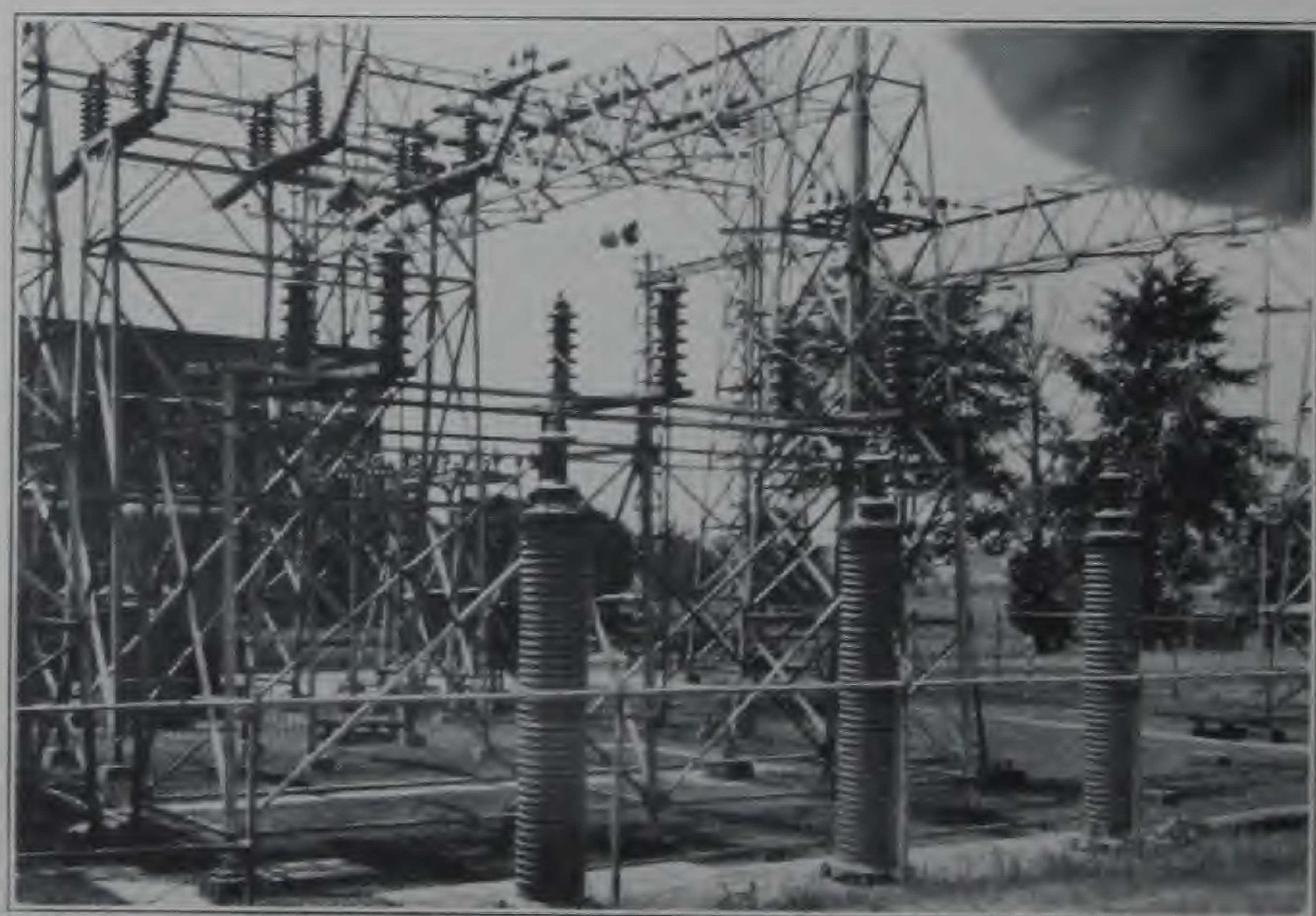
Oil Films: After the proper adjustment is secured add an oil film to prevent evaporation of the water. The oil may be poured in through the filling plug, using about one-half pint of oil in the 11-inch tanks, one pint in the 15-inch tanks and one quart of oil in the 20-inch tanks. This small amount of oil does not constitute any fire hazard, and more oil than this is unnecessary. If the weather is such that freezing is likely, also fill the water gauge with oil. This is done by unscrewing the cap on top of the gauge glass, being careful not to lose the fibre washers. Hold the gauge glass down against the bottom washer and pour in two or three tablespoonfuls of light machine oil, then replace the top washer and the cap. This will prevent the formation of ice in the gauge glass while still giving an indication of the water level inside the tank. Oil should not be allowed inside the bushing. If it is necessary to lift up a bushing and replace it after oil has been put on the surface of the water, all the oil may be skimmed away or else a cone of paper may be held over the end of the bushing as it is passed through the oil layer.

Whenever a tank is emptied it is advisable to flush it out before refilling, in order to remove any oil which may remain from the previous filling. The tanks may then be refilled, adding the oil film afterwards.

Installation—*Continued*

INSPECTION: Arresters first placed in service should be inspected after the first few days to see that everything is in good condition. In doing this each gap may be artificially short-circuited by a switch stick so that the arrester discharges. The height of the water in each tank should be noted also.

After first inspection it is generally found ample to inspect and test the equipment in the same way once every two or three months. All that is necessary is to see that the water is midway in the water gauge and then discharge the arrester a few times by a switch stick or other suitable insulated means.



Type G-84—110,000 Volts

Theory and Engineering Detail Pertinent to Bennett Lightning Arresters

THE ideal lightning arrester would be one without an air gap which would sift out all transient potentials or superpotentials from the line and at the same time interrupt the dynamic current which follows a discharge. Impulses or oscillatory discharges superimposed upon the exposed transmission line naturally subject all of the line insulators, transformers and auxiliary equipment to this impulse or wave impact. The insulating materials have some appreciable power to withstand stresses without rupture for an interval of time until the superpotential is dissipated by grounding through the arrester.

However, all high-voltage alternating-current lightning arresters must necessarily have a spark gap between the line and the interrupting device and ground. If the spark gap can be set at slightly above line potential under all conditions of operation, it is apparent the device will have considerably greater protecting qualities since it will start earlier to drain the line of impulses.

The earlier installations of lightning arresters used horn gaps ahead of the arrester equipment. By some very exhaustive experimental research there was discovered the now well-known impulse ratio, which denotes the ratio of the impulse breakdown voltage of the gap to a continuously applied breakdown voltage. As a result of these data, the shape of the electrode best suited to all conditions was found to be a sphere. As the breakdown voltage of a sphere gap is very much influenced by the presence of rain or other moisture, it should not be used outdoors unless protected, as a wet spacing has to be given to it which requires nearly double the voltage to break down when dry.

WHY THE BENNETT LIGHTNING ARRESTER FUNCTIONS UNIFORMLY IN WET AND DRY WEATHER

The Bennett Compensated Impulse Gap has nearly the same arc-over voltage when wet as when dry, and it has a lower arc-over voltage for impulse potentials than for normal frequencies. These are the advantages that make it unusual and most valuable in service. It may be set for dry conditions under normal voltage at 60 cycles without danger of discharging at lower potentials in wet weather. High-frequency disturbances will dissipate themselves through the gap and arrester even before reaching line-voltage value.

Theory and Engineering Detail—*Continued*

Each unit of the compensated impulse gap consists of a brass-pointed terminal about 1¼ in. (32 mm.) in diameter, mounted in the center of a convex disc of especially designed highly refractory porous porcelain which remains unaffected by the arc heat even if repeatedly applied. On the outer rim of this porcelain disc there is a metallic ring with a projection on the top to form an arcing horn. Back of the porous porcelain disc is an adjustable shield, which can be moved closer to the porcelain or away from it to increase the sensitiveness of the device to impulse potentials. The entire gap is supported from a 11/16 in. (17.4 mm.) shaft.

By use of the specially prepared and fired porous porcelain a non-metallic surface is presented to the raindrops or moisture, which are instantly spread or absorbed entirely, preventing the retention of drops of water in the gap path. They then do not offer a point for flux concentration or shorten the gap distance, as is the case where all metallic terminals are used. The importance of this characteristic can be appreciated, especially with gaps of short spacing, where the presence of a drop of water may so decrease the gap spacing as to cause the gap to break down at a very much less potential than that for which it is set, with the consequent unnecessary disturbance of service supplied by the circuit. Collection of moisture in the form of drops, which are so often formed on metallic surfaces during foggy or damp weather, even when it is not raining, is impossible on porous porcelain, and the compensated gap will, therefore, not operate at normal line potential due to this cause.

By the use of refractory porous porcelain that is not affected by the high temperature of the arc, the pitting and roughening of the surface that is always found in sphere or horn gaps after continued service is also avoided and the gap setting does not change its characteristics owing to any roughening effect. With metallic spheres it is not unusual, in short gaps, to find globules of melted metal that will represent 10 per cent of the gap setting and reduce the normal breakdown potential by that amount. In the case of large spheres with wide setting the whole nature of the gap is changed by this roughening or pitting, and instead of presenting a smooth polished surface to the charge, it soon becomes a series of points whose characteristic breakdown potential is entirely different from that of the original gap. This also has a tendency to fix the discharge at one point on the sphere, resulting eventually in actually burning holes through the metal or destroying it entirely. This does not occur in the compensated impulse gap, as is apparent on reference to the photograph of the gap. The fact that has the greatest bearing on the service performed by a line on which the compensated impulse gaps are installed, and which involves all the characteristics of the gap, is the ability to set the gap close to normal line voltage instead of being forced to give it a setting of double the normal

Theory and Engineering Detail—*Continued*

voltage value in order to prevent it from operating when there is no necessity. The compensated impulse gap may be set so that it will break down at the required potential under all conditions and only discharge at the time when a discharge is necessary to protect the circuit from unusual conditions or disturbances.

DISCHARGE SURFACE OF THE BENNETT GAP INCREASES WHEN MOISTURE IS PRESENT

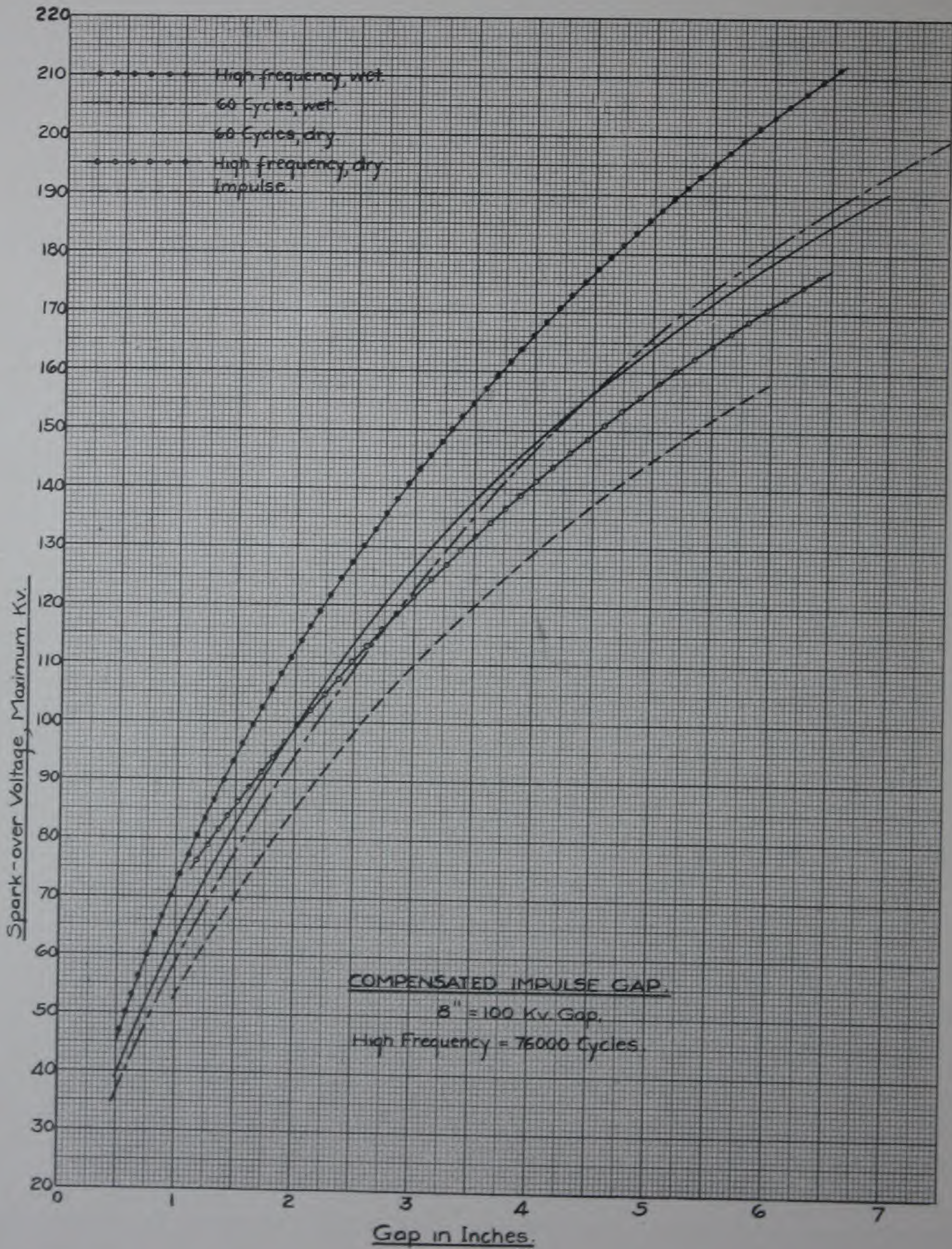
The functioning of this device under wet and dry conditions and impulse voltage is as follows:

It is well known that at ordinary commercial frequencies spheres of large diameter have a higher arc-over voltage for a given spacing than spheres with small diameter. In this new type of gap, when the porcelain is dry, the discharge area is equal to that of the brass point in the center, but when it is wet the porcelain acts more nearly as a conductor instead of an insulator and thus increases the available discharge area. In other words, this gap compensates for weather conditions by automatically replacing the small spheres or points with a large spherical terminal with no change in spacing; due to the absorption of moisture by the porcelain disc, the porous porcelain, although a good insulator when dry, becoming a conductor when wet. These porcelain discs dry out almost immediately after a rain owing to the hysteresis effect caused by the electrostatic field always present at the gap when in service. Though the moisture in the air manifestly decreases the arc-over voltage value in the usual horn or sphere gap, it increases the arc-over value of these gaps somewhat as the larger disc of wet porcelain is equivalent to and takes on the characteristics of a large sphere. Thus gaps, as shown in the curves, have a higher breakdown value when wet than when dry, a most desirable function.

In the design of the compensated impulse gap it was desired to obtain a gap that would have an impulse breakdown voltage less than that of ordinary sphere gaps under dry-weather conditions. *It is on the approach of a storm when the gaps are dry that the greatest stresses are often produced on equipment;* the insulators being dry, they do not absorb or tend to dissipate transient potentials as when all the insulators are wet. The potential gradient over insulators, bushings, etc., is considerably less when wet, and they can stand greater shock, as each unit is less likely to be subjected to overstressing. It is necessary, therefore, that a perfect gap should function upon the slightest voltage ripple due to switching surges, induced lightning potentials, static or impulses of any sort during dry-weather conditions.

As indicated in the curves, the dry-weather impulse potential curve of the compensated impulse gap is considerably lower than the 60-cycle continuously

Theory and Engineering Detail—*Continued*



Theory and Engineering Detail—*Continued*

applied breakdown voltage, but can be adjusted in relative value. There are two adjustments on the gap which control the sensitiveness. One is accomplished by moving the adjustable metallic plates. When these plates are moved closer to the porcelain disc the sphere-gap characteristics under impulse potentials are obtained and the gap is less sensitive to impulse of high-frequency disturbances.

Spark-over Voltages of Compensated Gap

Voltage of System	120 Per Cent Voltage or Setting for Wet-Weather 60 Cycles	Dry-Weather 60-Cycle Breakdown	Dry-Weather Impulse Breakdown	Wet-Weather Impulse Breakdown
33 Kv.	40	41	35	50
44 Kv.	53	55	48	66
66 Kv.	73	77	67	85
88 Kv.	106	106	93	120
110 Kv.	132	131	115	150

THEORY OF OPERATION OF COMPENSATED GAP

When the plates are close to the porcelain the total flux between the gap has been largely increased because of the greater capacity brought about by bringing the two comparatively large metallic plates closer toward the center of the gap, but the unit stress between the faces of the gap due to increased flux density has been decreased because of the approach to a sphere gap, and a greater impulse potential is required for spark-over. In other words, the dielectric between the electrodes, which includes the porcelain and air, is more uniformly stressed and therefore requires more potential to over-stress or break down the gap.

By revolving the metallic plates away from the rear of the porcelain discs we obtain a highly sensitive setting to impulse potentials, since when the metallic shields are moved back from the porcelain disc the electrostatic capacity over the gap and the flux about the center points have been increased. Therefore the air around the points becomes more quickly over-stressed, and as a result a more instantaneous breakdown occurs and at a lower potential than with the other setting, which is very similar to that of a sphere.

The moving of the adjusting plates forward and backward from the porous porcelain disc, when wet, does not influence the high-frequency or 60-cycle gap setting, the breakdown then following very nearly the characteristics of a large sphere.

The successful gap and lightning arrester must have very little time lag in order to protect apparatus from harm when subjected to impulse potentials.

Theory and Engineering Detail—*Continued*

An impulse voltage reflected upon electrical apparatus must involve the use of time and energy in order to rupture insulation. The destructive discharge through a dielectric requires not merely a sufficiently high voltage but a definite amount of energy. The destructive discharge does not occur instantly with its application, but a finite, though usually small, time elapses after the application of the voltage before the discharge occurs. During this time interval energy must be supplied to the dielectric. As a result, therefore, the perfect gap and arrester combination should function at the beginning of this period in order to absorb and dissipate disruptive energy and at the same time prevent its entering the apparatus which is to be protected.

If the arrester combination has a perceptible time lag, the impulse energy will be applied to the dielectric for a part of a time at a given rate and overstressing of the dielectric of the apparatus is sure to occur. Continual subjection to overstressing will cause injury and ultimate breakdown of such apparatus.

The compensated impulse gap fulfills all requirements of the ideal gap. It does not change its normal frequency breakdown value when wet or dry and can, therefore, have the close dry setting slightly above normal line potential with the assurance that it will not discharge at less than line potential when wet. It does not need protection by covering and is set up in free air with nothing to restrict its ventilation.

It will discharge impulse or high-frequency disturbances at their inception, giving them the least chance to rise to destructive values. *Its impulse value and its normal frequency value are capable of calibration independently of each other.* It presents a fixed breakdown value to all discharges even under the heaviest rainfall and needs no weather protection for this function.

Elpeco's New Factory

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